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Dredging Operations and Environmental Research Program

Fishery Resource Utilization of an Estuarine Borrow Pit in Mobile Bay, Alabama

Kevin J. Reine, Douglas G. Clarke, and Gary L. Ray

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Abstract

Many inshore coastal habitats have been altered by sand excavation for commercial and beach nourishment purposes, producing artificial holes and depressions. These features are characterized by poor sediment, water quality, altered circulation patterns, water column stratification, and the accumulation of fine sediments. These parameters are frequently cited as factors for degraded habitat found in borrow pits. This report summarizes the results of baseline and Year 1 postrestoration monitoring of Brookley (partially restored) and Airport Holes (control), located in Mobile Bay, Alabama. Monitoring efforts included a combination of fisheries acoustic techniques to determine fish density and spatial and temporal distribution patterns, conventional fisheries to determine species composition, length, CPUE, water quality, and sediment grain size analysis. Benthic macro-invertebrates were sampled seasonally to evaluate recruitment and community structure. Postrestoration results indicated a significant improvement in water quality conditions in Brookley Hole. Hypoxic/anoxic conditions present during prerestoration were absent during postrestoration sampling. Prerestoration infaunal sampling indicated that both holes supported impoverished benthic assemblages comprised largely of opportunistic, disturbance-adapted infauna. Species abundance increased significantly during postrestoration sampling; however, it was still depressed when compared to the surrounding bay waters. One contributing factor is that water depths in Brookley Hole are still greater than the surrounding bay waters. There was no significant difference in abundance, taxa, or species composition among sites or the pre- and postplacement time periods, indicating that finfish utilization was not affected by the placement of dredged material. Brookley Hole remains a suitable candidate for either partial or complete filling with dredged material.

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Preface

This borrow pit restoration study was a joint effort between the U.S. Army Engineer Research and Development Center (ERDC) and the U.S. Army Engineer Mobile District, under the Dredging and Operations and Environmental Research (DOER) Program.

Principal Investigators for this study were Kevin J. Reine and Dr. Douglas Clarke of the Wetlands and Coastal Ecology Branch (W&CEB) of the Ecosystem Evaluation and Engineering Division, U.S. Army Engineer Research and Development Center, Environmental Laboratory. At the time of publication, Patricia Tuminello was Acting Chief, CEERD-EE-W; Mark Farr was Acting Chief, CEERD-EE-E; the Deputy Director of ERDC-Environmental Laboratory was Dr. Jack Davis (CEERD-EV-A), and the Director was Dr. Beth Fleming (CEERD-EV-Z).

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Col Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffrey P. Holland was the Director.

Acronyms and Abbreviations

AH	Airport Hole
AN	Airport Hole Natural Bottom
ANOVA	Analysis of Variance
BH	Brookley Hole
BN	Brookley Hole Natural Bottom
BU	Beneficial Uses
CL	Clay
Cm	Centimeters
CPUE	Catch per Unit Effort
dB	Decibels
DO	Dissolved Oxygen
ERDC	Engineer Research and Development Center
GR	Gravel
H	Halocline
HADAS	Hydracoustic Data Analysis Software
IWG	Interagency Working Group
LPIL	Lowest Practical Identification Level
M	Mud
MC	Moisture Content
Mg/l	Milligrams per liter
ms	Milliseconds
MS	Muddy Sand
MLLW	Mean Low Low Water
nMDS	Non-metric Multi-dimensional Scaling
NY/NJ	New York-New Jersey Harbor
OR	Organics
PTG	Primary Textural Group
PPT	Parts per Thousand
SAV	Submerged Aquatic Vegetation
SD	Sand

SM	Sandy Mud
SPI	Sediment Profiler Imagery
SS	Sandy Silt
ST	Silt
TL	Total Length
TS	Target Strength
TCG	Time Varied Gain
USACE	United States Army Corps of Engineers
μ	Microns

1 Introduction

Many harbor and inshore coastal habitats have been altered extensively by sand excavation for commercial aggregate and beach nourishment purposes producing artificial pits, holes, and depressions. These features can be found in a majority of estuaries and coastal embayments. In many cases, these borrow sites are characterized by poor sediment and water quality (e.g., hypoxia, anoxia). Many borrow sites were created in bay areas that have low velocity water currents, which allows fine sediment to accumulate in pit basins. Poor water circulation induces anaerobic decomposition and the production of hydrogen sulfide gas. Water column stratification is also frequently cited as a contributing factor in degraded habitat. These factors, in turn, deplete near bottom dissolved oxygen. To date, few prior studies exist that examine the effects of dredged material placement in estuarine borrow pits.

Clarke et al. (1998) examined spatial and temporal fish utilization patterns, dissolved oxygen concentrations, and benthic assemblages of the CAC Pit, in Lower Bay, New York to collect baseline data for comparison to post-restoration results. The authors concluded that fishes in the CAC Pit and the nearby reference area were not sufficiently different to support a conclusion that the pit was either depauperate or “packed” with fishes or that there was a substantive differential use of the borrow pit as opposed to surrounding waters. Evidence did not support the theory that fishes utilized the CAC Pit as overwintering habitat. Changes to the benthic assemblages were examined through the use of sediment profile imagery (SPI). The authors concluded that the CAC Pit represents a very different sedimentary environment than historical or existing surrounding bottom conditions. SPI characterization of the CAC Pit was consistent with previous studies conducted by SAIC (1996). This included deep camera penetration into soft sediments and reduced sediments beneath oxidized layers at all stations sampled. The presence of methane gas packets, very high sedimentation rates and the featureless seafloor within the borrow pit likely contribute to altered invertebrate assemblages. In terms of benthos, however, the CAC Pit does appear to support a persistent population of macroinvertebrates with affinities for “soft” unconsolidated substrates. Dissimilar to a study conducted by Conover et al. (1985), which reported dissolved oxygen (DO) concentrations (mg/l) to near hypoxic levels, DO

levels measured by Clarke et al. (1998) did not fall below 5 mg/l. To date, the CAC Pit has not been restored.

Yozzo et al. (2004) reported similar conditions for multiple borrow sites located in Lower NY/NJ Harbor. Borrow pits in NY/NJ Harbor (e.g., CAC Pit and North and South Hoffman-Swinburne Pits) and Jamaica Bay (e.g., Little Bay and Norton Basin) were generally characterized by deep water, reduced hydrodynamic exchanges, altered sedimentation patterns, and biological communities. Wind-wave-induced current velocities also tended to increase when passing over deep waters of a borrow pit, enhancing the strength of waves reaching adjacent shorelines. In Jamaica Bay, pits are located in sheltered basins not subject to strong tidal currents, which results in persistent hypoxic conditions. Bokuniewicz et al. (1986) and Cerrato et al. (1989) reported significantly lower abundance and diversity of infaunal and epifaunal organisms for borrow pits within the New York Bight when compared to adjacent control sites.

At Morris Cove, New Haven Harbor, CT, baseline studies — including multibeam bathymetry to map the contours of the pit, SPI techniques to characterize benthic habitat, and water quality surveys — were completed in 2011 to assess the overall "health" of the borrow site. Results from previous studies indicated that the deeper, less flushed waters within the borrow pit often became anoxic during the late summer months. The results of the 2011 survey indicate that the degraded biological conditions within the borrow pit will likely remain for the foreseeable future and that there is opportunity for approximately 43 acres of habitat restoration if the pit were filled in and return to its preexcavation contours eliminating the potential for site-specific anoxic conditions (AECOM 2012). The authors concluded that the restored borrow pit area would increase available shellfish habitat and potentially provide additional winter flounder spawning and nursery grounds.

Murawski (1969) reported that 21 of the 38 dredged holes in Barnegat Bay, NJ had low dissolved oxygen and high hydrogen sulfide concentrations, and that 20 of the 38 dredged holes were devoid of benthic invertebrates. When benthic invertebrates are present, they are generally represented by pollution indicator species, such as the annelid polychaetes *Capitella capitata* or *Streblospio benedicti* (Culter and Truitt 1997). In 1992, the New Jersey Department of Environmental Protection (NJDEP) resurveyed the Barnegat Bay dredged holes (cited in USACE 2001) and found that they

contained water quality conditions that did not differ substantially from those reported by Murawski (1969). Reine et al. (2012) studied the effects of a partial restoration of Dredged Hole #6 located in Barnegat Bay, NJ. Results were compared to an unrestored pit (Dredged Hole #5) located approximately 1.5 km to the south. Dredged Hole #6 was filled to an elevation of -5.5 m (-18 ft) MLW by placing dredged material derived from n nearby navigation channel using a hydraulic pipeline cutterhead dredge. The final restoration design included formation of six mounds in the elevated basin of the hole to add relief and increase bathymetric complexity of the borrow pit basin. By mounding the sediments during the dredge-and-fill operation, it was theorized that the tops of mound sides would provide conditions suitable to sustain and support a healthy and diverse benthic invertebrate community. Dredged sediments consisted primarily of sandy material with 70 to 90% coarse fractions. Approximately 96,000 cubic meters (125,000 cubic yards) of dredged material was pumped into Dredged Hole #6. A minimum of one meter of sand was placed over the underlying fine-grained sediment as a foundation for creation of sand mounds. No evidence of hypoxia or water column stratification was evident post-restoration. The number of benthic taxa per sample and animals per sample were significantly higher ($p<0.05$) postrestoration.

Dredged holes with similar water quality conditions and depauperate benthic assemblages can be found throughout Florida’s bays and estuaries (e.g., Tampa Bay, Florida), as well as along the northern Gulf of Mexico (e.g., Brookley and Airport Holes, Mobile, Alabama). The Tampa Bay Dredged Hole Habitat Assessment Advisory Team (2005) surveyed 16 dredged holes in Tampa Bay, Florida during summer and fall seasons and 14 holes during spring and early summer seasons. Density stratification was evident at some sites during all sampling periods. The authors also reported that dissolved oxygen concentrations were anoxic (< 0.2 ppm) at some sites and hypoxic (< 2 ppm) at others. Benthic assemblages were extremely degraded at seven holes during summer and fall 2002 and at five dredged holes during spring 2003.

From several perspectives, filling existing borrow pits represent a logistically and ecologically feasible restoration option. Borrow pits are potential placement sites for substantial volumes of dredged sediment, if navigation channels requiring periodic maintenance dredging lie within reasonable distances. Returning subtidal bottoms in the estuary to their historical depth contours could reestablish preexisting habitat attributes

and functions. Detractors opposed to filling dredged holes claim that existing pits provide valuable recreational fishing areas and critical over-wintering habitat for various fishery resources. Potential benefits and detriments of borrow pits are reviewed in Yozzo et al. (2004) and USACE (2012). These include: altered circulation and secondary effects on tidal ranges and wave energies, creation of sinks for deposition of fine sediment, oxygen depletion, altered benthic communities, and recreational fishing use. Previous characterizations of benthic resources in borrow pits have been undertaken by Cerrato and Scheier (1984), and Cerrato et al. (1989). Likewise, regional fishery resource use of borrow pits and surrounding open-water habitat have been assessed by Conover et al. (1985) and Woodhead and McCafferty (1986).

2 Background

In 2011, The Mobile Bay Interagency Working Group (IWG) selected Brookley Hole as a viable alternative as a locally preferred plan for beneficial use (BU) of dredged material from the Mobile Bay navigation channel (USACE 2012). Three filling scenarios were considered by the IWG: One alternative was to place enough material into the pit to bring the bottom elevation to a level where the basin would no longer exhibit hypoxic conditions, thereby returning some level of environmental productivity. This, in turn, would have allowed for both the reestablishment of benthic invertebrates in the pit basin while not adversely impacting the pit with regards to fish utilization or recreational fishing. A second alternative consisted of successive dredge and fill cycles to return the bathymetry to historical depth contours matching existing surrounding bottom habitat. Filling to this level would allow the bottom, following consolidation of the dredged material, to support establishment of natural communities, such as submerged aquatic vegetation (SAV) and oyster beds. A third alternative was to continue placement in successive dredging cycles until elevations were created that would support an emergent wetland. Such a feature would have provided a variety of habitats that could potentially support numerous birds, fish, and benthic communities. The consensus of the IWG was to fill Brookley Hole in stages. Postrestoration monitoring would then be used to evaluate the performance of the fill and to then decide on a final plan. The initial placement action consisted of pumping approximately 1.2 million cubic yards of fine-grained material from the upper reach of the Mobile Bay navigation channel into the deepest area of Brookley Hole. This was accomplished by using a 30-inch hydraulic cutterhead pipeline dredge. A submerged 30-inch pipeline ran east to west from the navigation channel to the Brookley Hole placement site. An anchored placement barge was tethered to the submerged line using approximately 1,000 feet (303 m) of floating pipeline. The placement barge was outfitted with a vertically down-turned terminus extending to a depth of approximately -15 ft (-4.5 m) MLLW for subaqueous placement within the hole. The dredged material slurry was discharged through the down-pipe fitted with a baffle plate to dissipate surge forces and enhance settling, approximately 5 feet (1.5 m) above the existing bottom.

Prior to restoration efforts, the Engineer Research and Development Center (ERDC) began a joint study in 2011 with the U.S. Army Corps of Engineers, Mobile District to assess habitat quality of Brookley Hole. For purposes of comparison, a nearby unrestored borrow pit, designated as Airport Hole, was identified as a reference site. Baseline data were collected in summer and fall 2011 and spring 2012, in each borrow pit and used to assess the overall "health" of each site by examining water quality, benthic invertebrate communities, and fishery assemblages. Year 1 post restoration monitoring began in October 2012 and concluded in August 2013.

It should be emphasized that the terms pre- and postrestoration with regards to Airport Hole refer to the time period in which monitoring occurred, as dredged material was not placed within the Airport Hole basin. When referring to Brookley Hole, these terms apply to the time period before and after dredged material placement. In addition, a comparison of pre- and postbenthic results (e.g., density, taxa per sample, animals per sample) are only available for the spring and summer sampling periods. A comparison of results for the fall monitoring period could not be made since unconsolidated sediments prevented collection of benthic samples in October 2013. The fall sampling event occurred less than 3 months after the placement of dredged material (July 2013) in the pit basin.

3 Methods

Study Site

Mobile Harbor, AL, is located in the southwestern part of the state, at the junction of the Mobile River with the head of the Mobile Bay. The port is about 28 nautical miles north of the bay entrance from the Gulf of Mexico and 170 nautical miles east of New Orleans, Louisiana. Both Brookley and Airport Holes are located SSW of McDuffie and Little Sand Islands, northeast of the inlet to Dog River and west of the Mobile Upper Bay Channel (Figure 1). Brookley Hole can be found at 30° 37.965 N and 88° 3.119 W. Airport Hole is located south of Brookley Hole in the vicinity of the Mobile Downtown Airport at 30° 36.376 N and 88° 03.149 W.

Figure 1. Study Site.

Water Quality

A calibrated YSI (Model 6920 V2) water quality sonde was used to measure DO concentrations (mg/l) and percent saturation, temperature (°C), and salinity (ppt) at approximately 1-m increments from surface to bottom in each dredged hole during each seasonal sampling event.

Sediments

Representative stations were sampled by Ponar Grab (area = 0.044 m^2) during December 2011 (prerestoration) and April and August 2013 (postrestoration) for sediment grain analysis. Grab samples were processed using a combination of wet sieving and floatation procedures (Folk 1968, Galehouse 1971). Samples were first soaked in a 20% sodium hexametaphosphate solution to disaggregate the silt and clay fractions; then agitated in a sonic bath for several minutes. The disaggregation procedure was repeated prior to pipette analysis to ensure complete separation of the silt and clay fractions. Sediment data analysis was conducted using Gradistat 8.0 (Blott 2000).

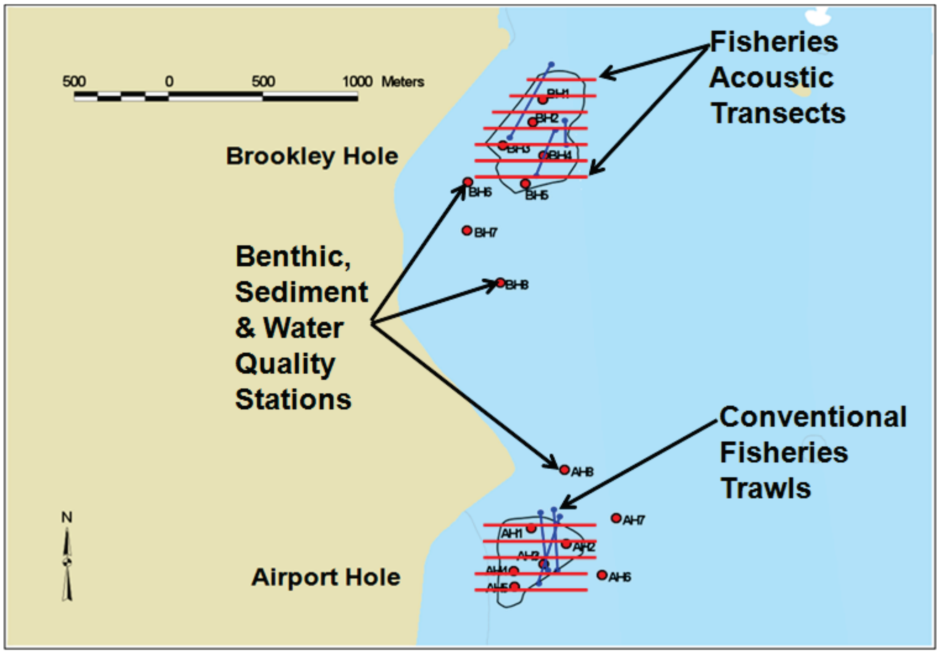
Benthic Sampling

Benthic macroinvertebrates were sampled seasonally to evaluate recruitment and community structure in each dredged hole. A total of 16 samples were taken during each seasonal survey. Of these, five samples were taken within the basin of each dredged hole (n = 10), and 3 samples were taken from the natural bottom (n = 6) along the periphery of each borrow pit. A layout of benthic sampling stations is presented in Figure 2. A successful sample required a minimum penetration depth into the bottom sediment of at least 6 cm. Samples were sieved in the field using a 0.5 mm mesh to remove excess sediment, then placed in individual fabric bags, and preserved in 10% buffered formalin. After transport to ERDC, samples were rinsed over a 0.5 mm mesh sieve, stained with rose Bengal, and stored in 70% ethanol until processed. Samples were subsequently examined using 3X illuminated magnification and organisms sorted from the sediments. All organisms were identified to the lowest practical identification level (LPIL) and counted.

Fishery Hydroacoustics

Prerestoration surveys were conducted in August and December 2011 and April 2012. Postrestoration monitoring was conducted in October 2012 and April and August 2013. Acoustic data were collected with a BioSonics DT 6000 digital echosounder equipped with 200-kHz split-beam transducer (6-degree conical beam angle at -3dB). Targets satisfying single target criteria with target strength (TS) above -52.6 dB (equivalent to a fish length of 4 cm) were accepted. The acoustic resolution (minimum target separation distance) of single targets was determined to be 0.23 m following $R = c\tau/2$

Figure 2. Schematic of hydroacoustic transects (red transects), conventional fisheries trawling (blue transects) and water quality, sediment and benthic stations (red circles). (Note: The number of fisheries acoustic transects exceeded that depicted in the schematic.)



(Simmonds and MacLennan 2005), where c = speed of sound in water (1,500 m s-1) and τ is pulse length duration (0.3 ms). Water temperature, salinity, and depth were measured at stations in each borrow pit for correct calculation of speed of sound and absorption coefficients. Before each sampling period, the hydroacoustic equipment was calibrated using a tungsten carbide sphere (38.1 mm diameter) standard target of known acoustic TS (~39.2 dB in seawater). The calibration was stable over all sampling periods. The transducer was mounted in a downward, vertical orientation on an adjustable aluminum frame affixed to the gunnels of the survey vessel. Acoustic data were collected and stored on a laptop computer running BioSonics Acquisition Program (version 4.1) software.

Postprocessing analyses were performed using Hydroacoustic Data Analysis Software (HADAS), developed by the ERDC. Data were collected during mobile surveys with boat speed limited to 5 km h-1. Each site was divided into parallel transects covering the full east to west footprint of each dredged hole (Figure 2). Eleven transects (mean length = 337 m) were occupied at Brookley Hole and 12 transects (mean length = 288 m) at Airport Hole. Total survey distance was 3.7 km (Brookley Hole) and 3.5 km (Airport Hole), respectively. During each seasonal survey, all transects were surveyed during daylight hours only. Relative fish density was estimated

using standard echo-integration techniques, which process the 20logR Time Varied Gain (TVG) signals. To determine absolute fish density values, the contribution of single fish (average backscattering cross section or σ) was measured. This value (σ) corresponds to the acoustic equivalent of the length of the insonified fish after conversion to target strength (TS). TS values (dB) were converted to fish length using a BioSonics variant of the dorsal-aspect equation developed by Love (1971). Based on the total and the mean echo strength per fish, the absolute number of fish can be calculated in the area insonified. Thus, every ping transmitted by the sounder provides a measurement of fish density, in fish per cubic meter, along each transect or within each cell (scaled to fish per 100 m^3).

Conventional Fisheries Gears

Otter trawls were used to examine fish assemblage taxonomic composition, and to provide ground truth data for the hydroacoustic surveys (Figure 2). Triplicate fish trawls using an 8-foot (2.4 m) shrimp trawl (mesh size 1¼ inch) were conducted seasonally within the deepest portion of each hole. Two of the three trawls were conducted in the deeper portion (6 m) of Brookley Hole. The third trawl was conducted at shallower depths (3-5 m). Airport Hole is relatively uniform in depth (2-3 m); therefore, all three trawls were conducted near the bottom of the pit basin. All fish collected were identified to species, counted, and total length (TL) measured to the nearest mm.

Conventional Fisheries Statistics

Data from trawls taken at Airport and Brookley Hole borrow sites were analyzed using Nonmetric multidimensional scaling (nMDS), a multivariate statistical technique and Heirarchical clustering. Both ordinations were performed using ranked similarity matrices based on Bray-Curtis similarity measures of log X+1 transformed data. PERMANOVA, a nonparametric form of ANOVA utilizing the individual similarity index values was performed to test for differences among areas and pre- and postrestoration time periods. Conventional fisheries data were analyzed using Primer version 6 (Clarke and Warwick 2001) and PERMANOVA+ for Primer (Anderson et al. 2008).

4 Results and Discussion

Water Quality

A summary of water quality parameters is presented in Table 1. Water quality measurements taken in spring and summer in 2011 in Brookley Hole indicated that DO concentrations decreased with water depth from a maximum of 7.8 mg/l (113.5% saturation) at surface to anoxic levels (0.11 mg/l at 1.6% saturation) in the lower 1 m of the water column (Figure 3). DO readings typically fell below the hypoxic level (< 3 mg/l) at prerestoration midwater depths of 3 to 4 m. Anoxic conditions were not present during the fall sampling; however, DO readings did fall to below hypoxic levels (<3 mg/l) at water depths greater than 4 m. The DO readings in the upper portion of the water column (< 2 m) ranged from slightly less than 6 mg/l (spring) to 9.1 mg/l (fall). There was no evidence of hypoxia/ anoxia during any of the three postrestoration surveys, as DO exceeded 6 mg/l (peak = 9.3 mg/l) at all depths. The trend of decreasing DO

Table 1. Water quality summary.

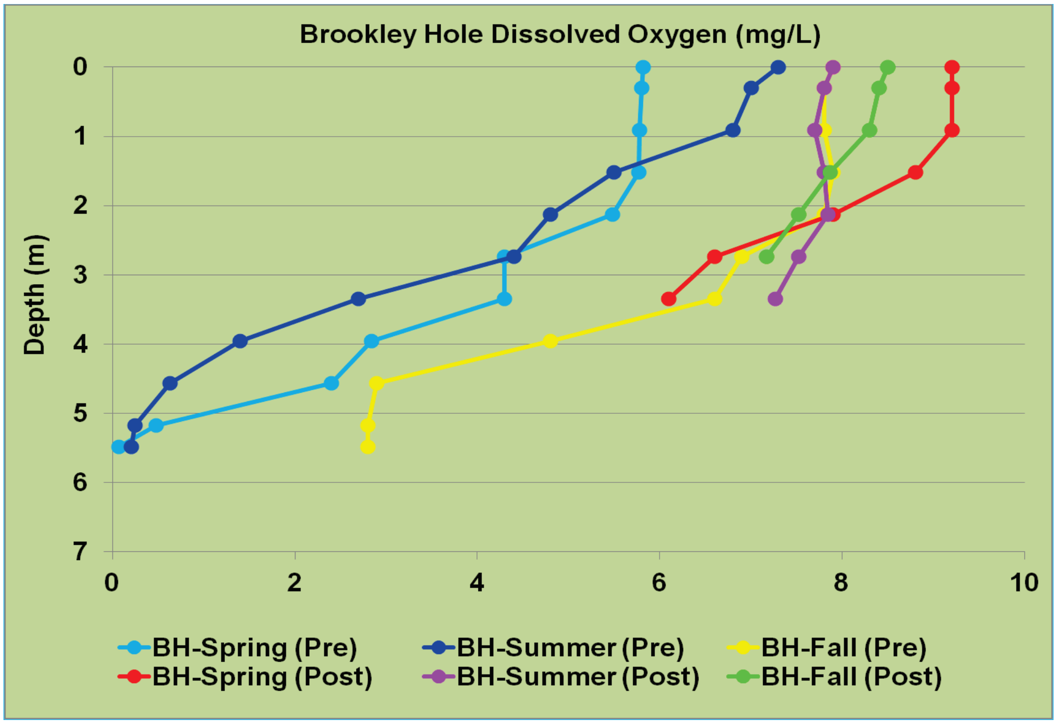
Season	Survey	Site	Dissolved Oxygen (mg/l)					Avg. Temp (°C)	Avg. Salinity (ppt)	Temp. or Salinity Stratification
			Range (mg/l)	Avg. (mg/l)	% Saturation Range	% Saturation Avg.	Hypoxic/ Anoxic			
Aug	P	BH	0.1-7.8	3.7	1-116	53.6	Yes[1,2]	29.8	18.8	No
Aug	P	AH	2.9-7.6	5.2	41-112	75.7	No	29.7	18.0	No
Aug	PR	BH	6.8-8.2	7.8	88-97	91.6	No	22.1	3.8	No
Aug	PR	AH	6.5-8.5	8.2	80-100	95.3	No	21.4	3.9	No
Nov	P	BH	2.9-9.1	6.1	29-94	63.1	Yes[1]	12.9	15.7	Yes (H)
Nov	P	AH	6.2-8.4	7.8	64.8-87	80.0	No	13.8	10.4	Yes (H)
Oct	PR	BH	7.2-8.7	8.0	82-106	91.6	No	19.4	9.4	No
Oct	PR	AH	3.5-10	7.9	28-123	91.4	No	19.4	10.2	No
Apr	P	BH	0.9-5.8	4.0	0.3-66	44.8	Yes[1,2]	19.6	3.9	Yes (H)
Apr	P	AH	5.8-6.0	5.9	66-69	67.4	No	21.6	1.8	No
Apr	PR	BH	6-9.3	7.5	64-90	75.8	No	13.8	5.2	Yes (H)
Apr	PR	AH	6-9.3	8.3	70-90	84.2	No	14.6	4.7	Yes (H)

BH = Brookley Hole; AH = Airport Hole; H = Halocline; P = Pre-restoration; PR = Post-restoration

[1]Hypoxic from mid- to lower water depths.

[2]Anoxic in the lower 1-meter of the pit basin.

Figure 3. DO (mg/l) concentrations during pre- and postrestoration sampling within Brookley Hole. (Note: Seasonal results are averaged across five stations occupied within the borrow pit.)



concentrations with increasing water depth also occurred at the much shallower Airport Hole. Maximum DO concentrations during summer fell from 7.6 mg/l at 112.2% saturation to 2.9 mg/l at 41.2% saturation at 2.7 m water depth (Figure 4). In Airport Hole, hypoxia occurred only during the summer monitoring period and only within the lower ½ m of the water column. The second lowest DO measurement (4.5 mg/l) occurred in fall 2013 and exceeded hypoxic levels. All other DO measurements exceeded 6 mg/l in the lower water column, peaking at nearly 10 mg/l at water depths of less than 1 m.

In Brookley Hole, a halocline was clearly present in both spring and fall during prerestoration monitoring. In spring, salinity measurements were fairly uniform from surface to 4 m water depth, averaging slightly less than 2 ppt. Salinity then increased to slightly greater than 10 ppt in the lower 2-m of the water column (Figure 5). In fall, prerestoration salinity increased from 5 to 10 ppt from surface to 2 m, before increasing by an additional 10 ppt from 2 to 3 m, peaking at nearly 24 ppt in the lower 1-m of the water column. Prerestoration monitoring during the summer season did not show any evidence of a halocline. During postrestoration monitoring, only the spring survey indicated the presence of a halocline with salinity increasing from 2.5 ppt near surface to 10 ppt near bottom. Both spring (mean = 3.8 ppt) and fall (mean = 9.4 ppt) postrestoration sampling

Figure 4. DO (mg/l) concentrations during pre- and postrestoration sampling within Airport Hole. (Note: Seasonal results are averaged across five stations occupied within the borrow pit.)

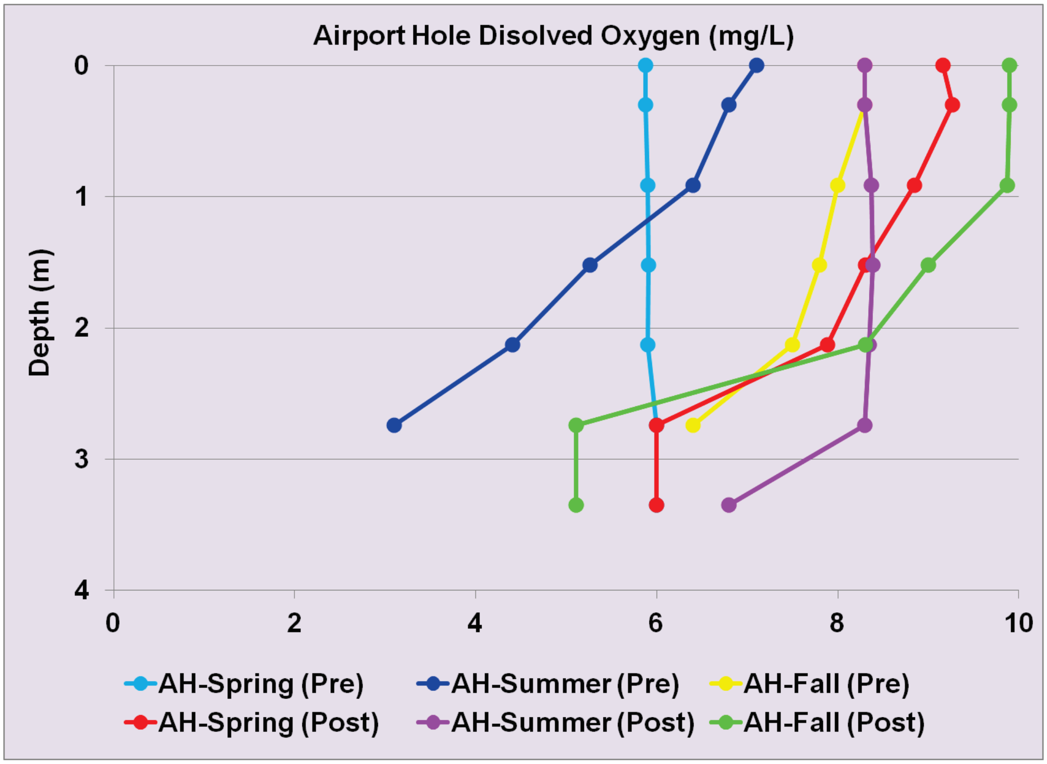
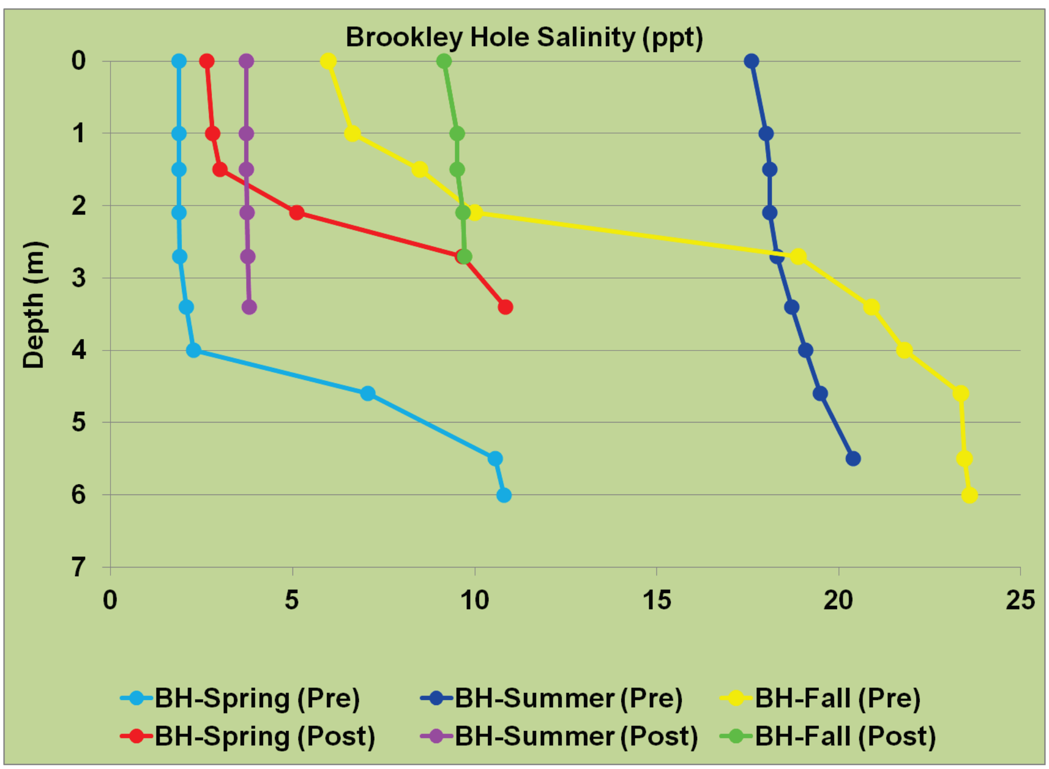


Figure 5. Salinity (ppt) concentrations during pre- and postrestoration sampling within Brookley Hole. (Note: Seasonal results are averaged across five stations occupied within the borrow pit.)



indicated the absence of stratification, with nearly uniform surface to bottom salinities. At Airport Hole, water column stratification was present during fall 2011 and spring 2013. Salinity tended to increase by as much as 5 ppt from measurements taken at 1.5 m and 2 m water depth (Figure 6). At both borrow sites, stratification was absent only during summer sampling (August); although pre- (mean = 18 ppt) and post (< 5 ppt) monitoring measurements differed substantially. Maximum salinities in both dredged holes were in the low mesohaline range (5-12 ppt) during most sampling periods in the current study. The only notable exception was during summer.

Postrestoration water temperatures during spring were 5.8 (Brookley Hole) to 7 (Airport Hole) degrees cooler than corresponding water temperatures measured during prerestoration monitoring during the same week of the previous year (Table 1). A similar pattern of cooler postrestoration water temperatures occurred during summer. Pre- to postrestoration temperatures differed by as much as 7.7 and 8.3 degrees in Brookley and Airport Holes, respectively, although postrestoration sampling occurred 12 days later than prerestoration surveys. Pre- and postrestoration water temperatures are presented in Figures 7 (BH) and 8 (AH).

Figure 6. Salinity (ppt) concentrations during pre- and postrestoration sampling within Airport Hole. (Note: Seasonal results are averaged across five stations occupied within the borrow pit.)

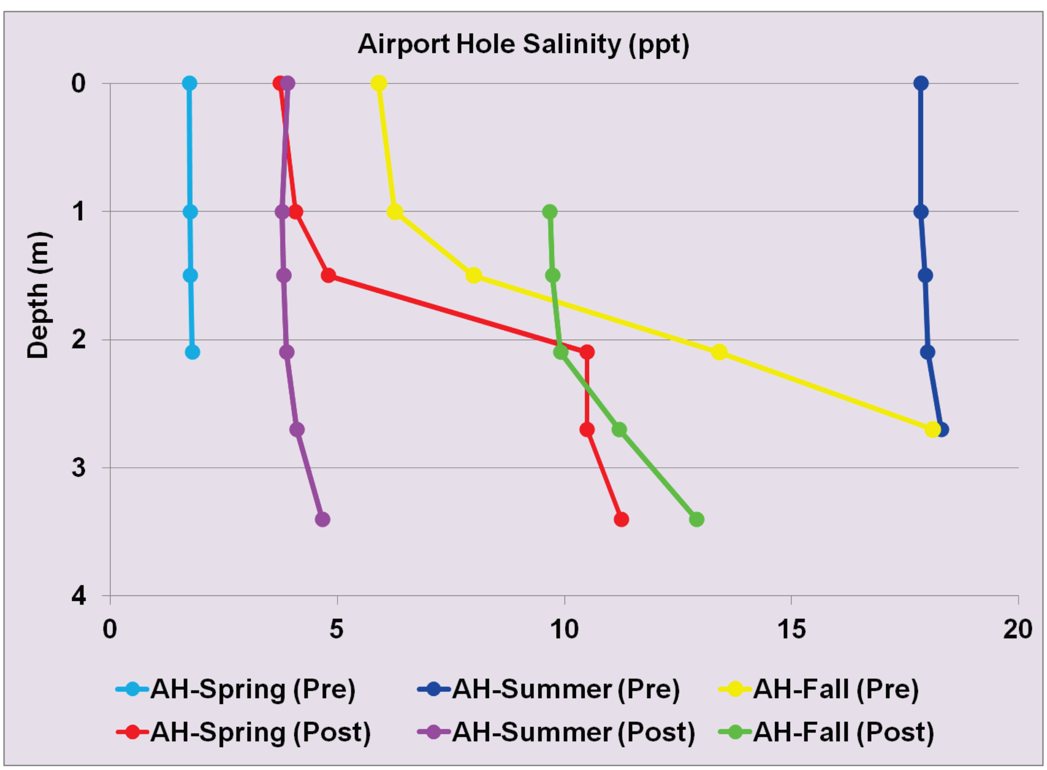


Figure 7. Water temperature (°C) during pre- and postrestoration sampling within Brookley Hole. (Note: Seasonal results are averaged across five stations occupied within the borrow pit.)

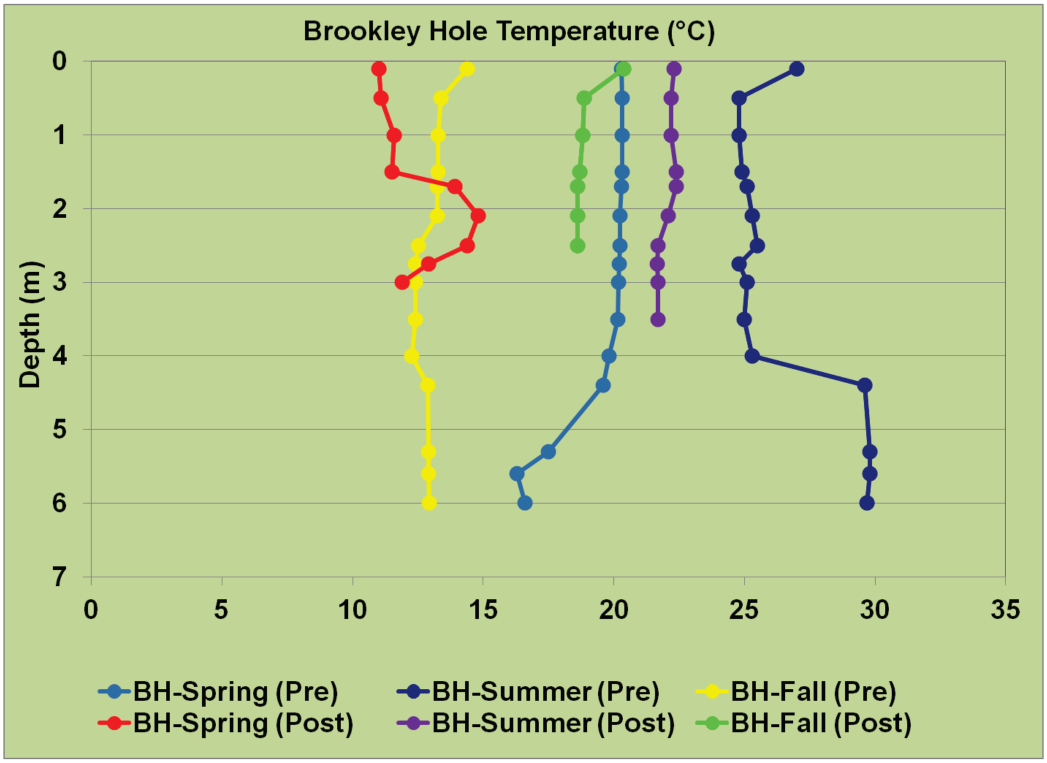
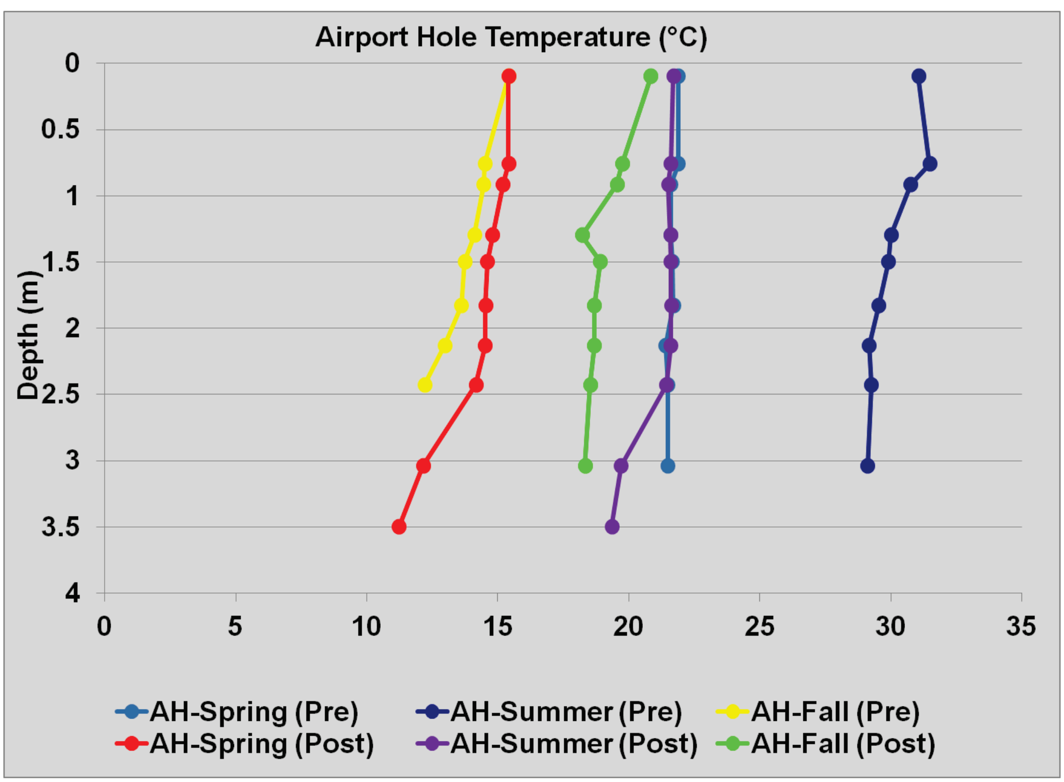


Figure 8. Water temperature (°C) during pre- and postrestoration sampling within Airport Hole. (Note: Seasonal results are averaged across five stations occupied within the borrow pit.)



Sediment Grain Size Analysis

A summary of sediment characteristics for both the natural bottom and borrow pit basins is presented in Table 2. Sediment composition (% total by sediment fraction) for prerestoration (December 2011) samples is presented in Figure 9 and for postrestoration in Figures 10 and 11 (April and August 2013, respectively). The percent of silt + clay is defined as the contribution of fine-grained sediment (< 63 microns) to a sediment sample. The primary textural group of all bottom samples from the two borrow sites can be characterized as mud with fine to medium silt as the mean sediment type. For samples collected in the natural bay bottom surrounding the pit basin, the primary textural group was muddy sand with a mean sediment type consisting mostly of very fine to medium sand (Table 2). Natural bay bottom sediment samples consisted of 59- to 80-percent sand, while borrow pit samples consisted of 89- to 100-percent fine-grained sediment (particle size diameter < 63 microns). When present, the fraction of the sediment sample in either pit basin that was comprised of sand ranged from 4- to 11-percent. The percent silt fraction from the natural bottom samples ranged from 20% to 25%, with two exceptions. The first occurred in Brookley Hole during August 2013, where the sand fraction was absent from all bottom samples (Figure 11). The second occurred in April 2013 for samples collected in the natural bay bottom around the periphery of the Brookley Basin where the sand fraction decreased to 59% (typically 75 to 80 percent) and the silt fraction increased to 41% (typically 20-25%). Both exceptions occurred in Brookley Hole after the placement of dredged material. There was little overall difference in mean grain size (BH = 6.7µ; AH = 9µ) between borrow pits. Mean grain size in the natural bottom ranged from 115 to nearly 200 microns, with the exception of postrestoration results for April 2013, where mean sediment size averaged only 51 microns for samples taken around the periphery of Brookley Hole. Percent organic content was only slightly greater in Brookley Hole at 8.4% when compared to Airport Hole at 6.9%. Change in organic content was less than 0.5% between pre- and postrestoration samples. Natural bottom sediments typically had organic contents averaging 1%. Moisture content (211% to 291%) was 13% greater for samples taken from Brookley Hole when compared to Airport Hole when averaging across samples. The same result was found when comparing pre- and post- restoration samples. Moisture content averaged 30% (prerestoration) and around 60% postrestoration for natural bottom samples. Total solids were generally less than 400 g/L for both pit basins and from 900 to 1500 g/L for samples taken in the natural bottom.

Table 2. Summary of pre- and postrestoration sediment characteristics.

Site	Date	Grain Size (mean)	% GR	% SD	% ST	% CL	% OR	% MC	PTG	Mean Sediment Type
BH	12/2011	7.4	0.0	4	80	16	8.2	267	M	Medium Silt
AH	12/2011	9.2	0.0	8	77	15	7.0	240	M	Fine Silt
AN	12/2011	160	0.0	77	19	4	0.9	30	MS	Fine/Medium Sand
BN	12/2011	115	0.0	75	21	4	0.9	29	MS	Coarse Silt/Fine Sand
BH	04/2013	6.8	0.0	4	78	18	8.7	245	MD	Fine Silt
AH	04/2013	10	0.0	11	74	15	6.5	211	MD/SM	Medium Silt
BN	04/2013	51	0.0	59	33	8	2.3	75	MS/SS	Very Coarse Silt
BH	08/2013	5.9	0.0	1.7	77	21	8.4	291	M	Fine Silt
AH	08/2013	7.8	0.0	7	74	19	7.3	250	M	Fine/ Medium Silt
AN	08/2013	178	0.0	82	14	4	0.9	64	MS	Coarse Silt/Med. Sand
BN	08/2013	124	0.0	78	18	4	1.4	41	MS	Very Fine Sand

Legend: BH = Brookley Hole, AH = Airport Hole, BN = Natural Bay bottom samples taken around perimeter of Brookley Hole, AN = Natural bottom samples taken around perimeter of Airport Hole, GR = Gravel, SD = Sand, ST = Silt, CL = Clay, OR = Organics, MC = Moisture Content, PTG = Primary Textural Group, M = Mud, MS = Muddy Sand, SM = Sandy Mud, SS = Sandy Silt (Note: Prerestoration sediment samples taken in 2011, Postrestoration samples taken in 2013.)

Figure 9. Sediment composition (% total by sediment fraction) for December 2011 (Prerestoration).

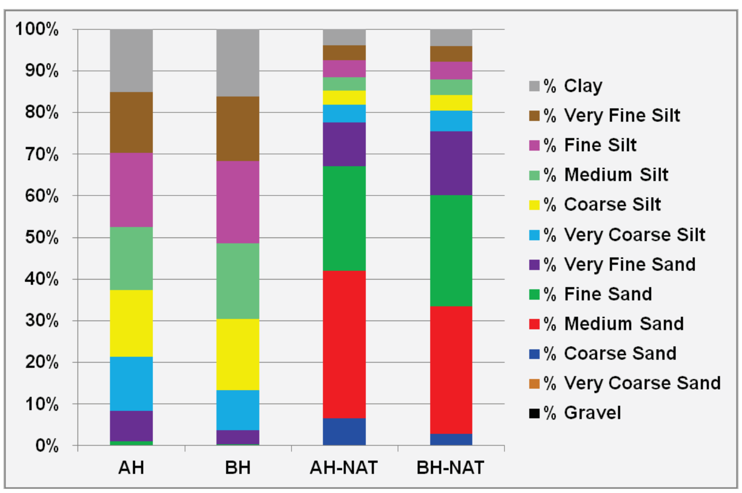


Figure 10. Sediment composition (% total by sediment fraction) for April 2013 (Postrestoration).

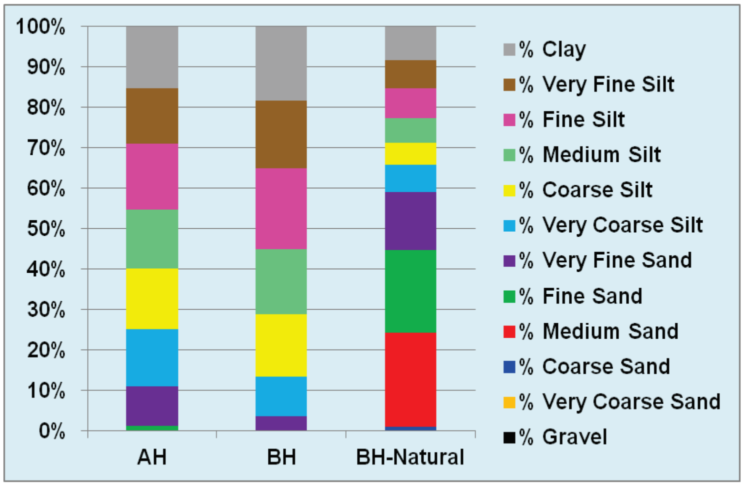
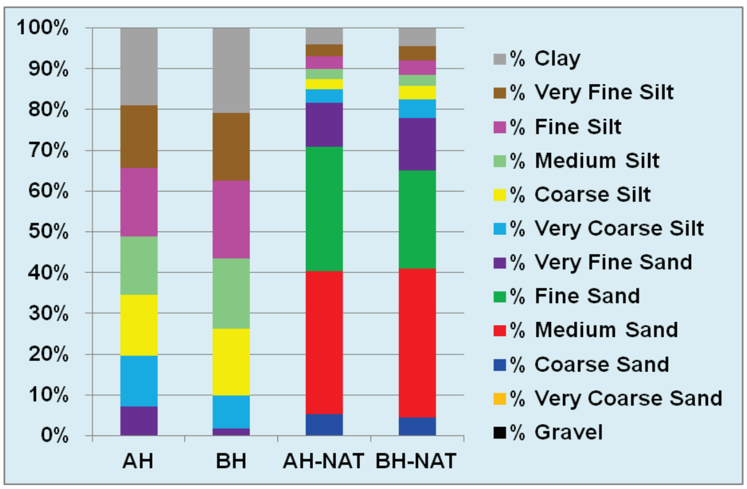


Figure 11. Sediment composition (% total by sediment fraction) for August 2013 (Postrestoration).



Benthic Community

Taxa and Abundance

Nearly four thousand (n = 3,948) specimens representing 38 taxa were collected over the course of the three prerestoration sampling events. Postrestoration sampling yielded similar results with 3,931 specimens representing 37 taxa. However, totals for prerestoration were based on three sampling events (spring, summer, and fall), whereas postrestoration totals were from two seasonal collections (spring and summer). A summary of taxa by season can be found in Appendix Table 1. Fall sampling (October 2012) did not occur during Year 1 postrestoration sampling, due to unconsolidated sediment within the Brookley Hole borrow site, given the

short timeframe in which sampling occurred after sediment placement. The prerestoration total (spring and summer only) decreased by 1,102 specimens collected in fall to 2,846 total specimens. Spring and summer combined totals would have nearly 1,086 fewer animals collected during prerestoration when compared to postrestoration sampling.

Spring

In BH, there was a significant ($p < 0.05$) increase in abundance during postrestoration sampling (Figure 12). Average number of animals per sample increased from 4 (pre) to 58 (post) during the spring sampling in BH. This reflected an increase in abundance from 91 to 1,317 animals per m^2. Density also increased at the natural bay bottom site during spring sampling from 3,541 pre- (combined average from Airport-Natural (AN) and Brookley-Natural (BN)) to 8,036 postrestoration (BN site only). Benthic sampling did not occur at the Airport natural bottom (AN) site due to inclement weather conditions. Airport Hole had the smallest increase in density from pre- (2,724 animals per m^2) to post (3,859 animals per m^2) restoration during spring. The yearly and/or seasonal variation in abundance at both Airport Hole and the natural bottom sites, however, cannot solely account for the significantly higher density in BH. Although there was a substantial increase in density and overall "health" of the BH benthic assemblage, it remains depressed after Year 1 postrestoration when compared to the natural bay bottom site. The result is either due to the benthic assemblage of BH having not fully recovered postplacement of dredged material or the basin depth in relation to the natural bay bottom is still sufficiently deep enough to prevent benthic recovery equivalent to that of the natural bottom. There was only a slight increase in the average number of taxa present in each sample for both Airport Hole (mean +1 increase) and the natural bay bottom (mean +3 increase). Average taxa increased by a factor of three from an average of 2.8 pre- to nearly 8 postrestoration in BH (Figure 13).

Summer

During the summer sampling, the number of animals per sample increased significantly ($p < 0.05$) from 2 (pre-) to 102 (postrestoration) per sample, resulting in an increase in density from 45 animals/m^2 to 2,315 animals/m^2. There was only a modest increase in abundance in AH, where the average number of animals per sample increased from 62 (pre) to 77 (post), resulting in an increase in density from 1,407 m^2 to 1,748 m^2 (Figure 14).

Figure 12. Average number of animals per sample for spring pre- and postrestoration sampling.

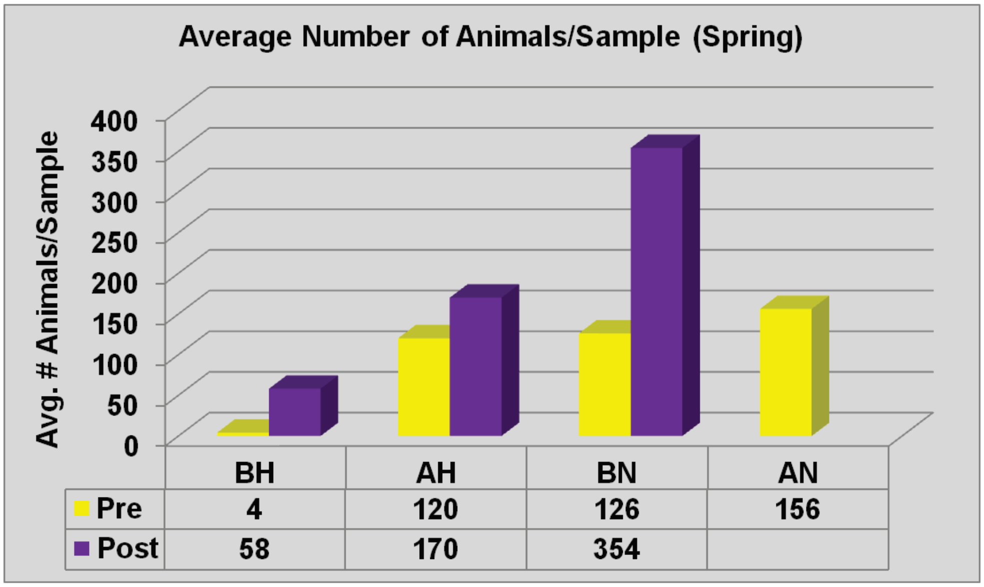


Figure 13. Average number of taxa per sample for spring pre- and postrestoration sampling.

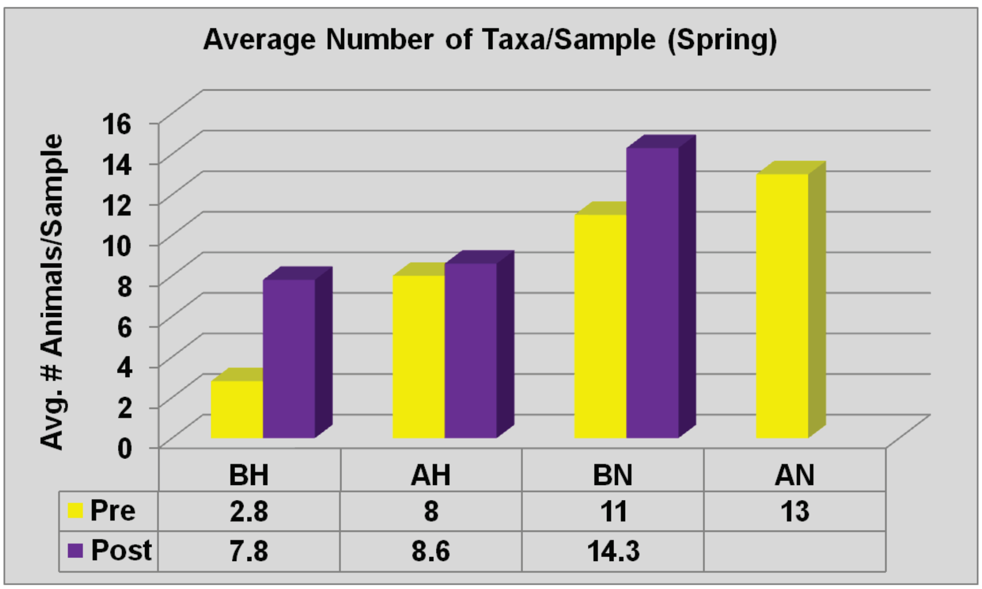
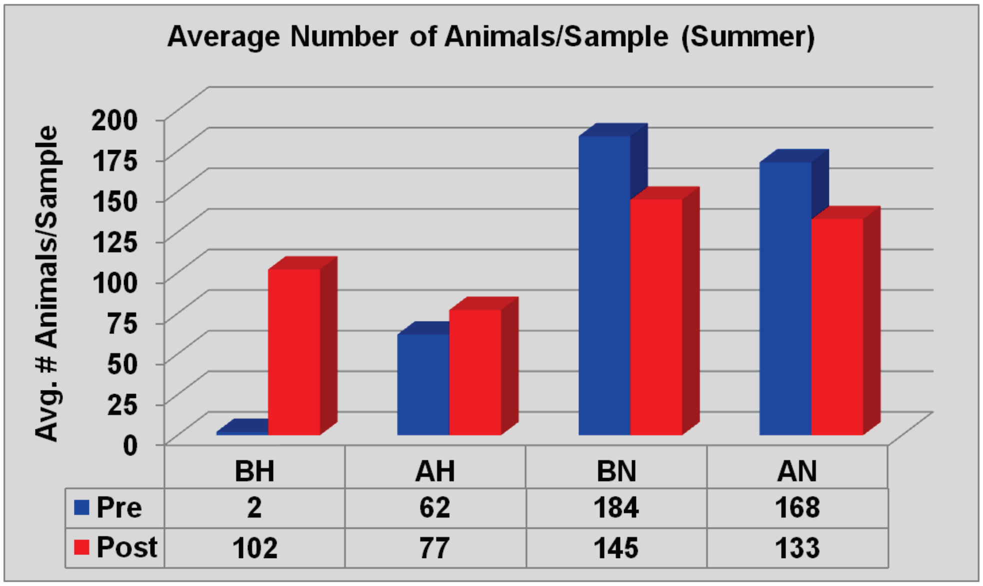
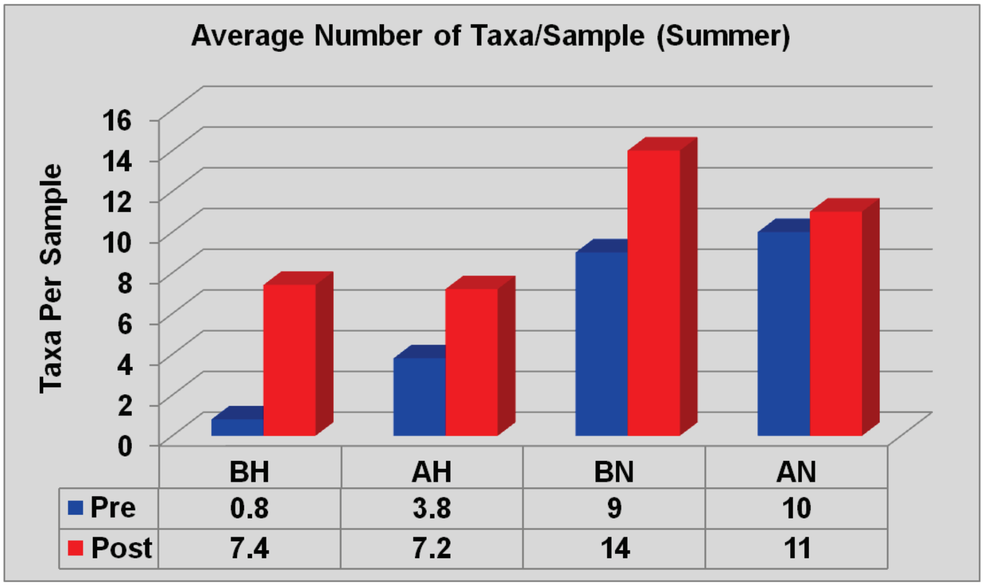


Figure 14. Average number of animals per sample for summer pre- and postrestoration sampling.



Postrestoration density in BH was still lower when compared to density of natural bottom (3,128 animals/m^2); however, density in BH exceeded density in Airport Hole (1,748 animals/m^2). Both natural bottom sites had a decrease in abundance during summer sampling. Density decreased slightly from 4,177 animals per m^2 to 3,392 animals m^2 (BN) and from 3,819 to 3,019 animals m/^{2} (AN) from the pre- to postrestoration time period. There was a greater variation in the average number of taxa present during summer sampling. Both natural bottom sites had an increase in the average number of taxa; although the increase was greater in samples taken around the periphery of Brookley Hole, which increased from an average of 9 to 14 taxa (Figure 15). The largest increase (average pre = 0.8, average post = 7.4 taxa) in the number of taxa in each sample occurred at BH. A similar pattern existed for AH, where the average number of taxa increased from 3.8 to 7.2 from pre- to postrestoration monitoring. By comparison, average number of taxa was eight per sample at Airport Hole during spring sampling, and increased by less than 1 taxon per sample, postrestoration (Figure 13). Water quality was a key factor in the lower number of taxa per sample at AH during the summer sampling event. DO concentrations were slightly below hypoxic levels during prerestoration summer sampling, but did not fall below 6 mg/l during summer postrestoration sampling. Although AH was much shallower than BH prior to restoration, the variation in DO concentrations indicates that AH is susceptible to adverse impacts to the benthic assemblage, particularity during times of calm weather when DO concentrations could fall below hypoxic levels.

Figure 15. Average number of taxa per sample for summer pre- and postrestoration sampling.



Species Assemblage

Prerestoration (Spring and Summer Only)

Collections at all three locations and two seasons (spring and summer) are summarized in Appendix Tables 2 and 3. Collections were heavily dominated by polychaetous annelids (Figures 16 and 17). The capitellid *Mediomastus* (LPIL) was the most abundant taxon (n =1,556) combined representing 54.7±0.8% of the spring and summer specimens collected. Other numerically dominant polychaetes during prerestoration sampling included *Streblospio* (LPIL, 15.3%), *Hobsonia florida* (8.5%), and *Capitella* (LPIL, 5.8%). Tubificid oligochaetes were the sixth most abundant taxon (2% of total) and were found principally on the natural bottoms. The clam *Macoma mitchelli* was the eighth most abundant taxon and made up 1.6% of all animals collected. This taxa was present in both the pre- and postrestoration benthic assemblage in Airport Hole and the postrestoration sampling in Brookley Hole (Figure 16b-d); however, the taxa was absent during prerestoration sampling in BH (Figure 16a). *Mulinia lateralis* (dwarf surf clam) comprised slightly less than 1% of the total abundance and was found primarily in samples collected from the natural bottom during postrestoration spring and summer sampling (Figures 16f and 17f). Two unidentified nemerteans were also commonly collected. The only amphipod to comprise more than 1% of total numbers of animals was *Cerapus* (LPIL); however, it was collected in abundance only in a single sample from the Brookley natural bottom site in August 2011. Although the amphipods

Ameroculodes (LPIL) and *Lepidactylus* (LPIL) did not make up more than 1% each of the total numbers, they did contribute significantly to abundance at the Airport natural bottom site in April 2012. This result was most likely due to the predominance of sandy sediments at the natural bottom sites.

Figure 16. Numerically dominant taxa collected during spring pre- and postrestoration sampling at each borrow site and the natural bay bottom. (Note: All graphs on the left side of the figure are prerestoration (April 2012), while graphs on the right side of the figure are postrestoration (April 2013).

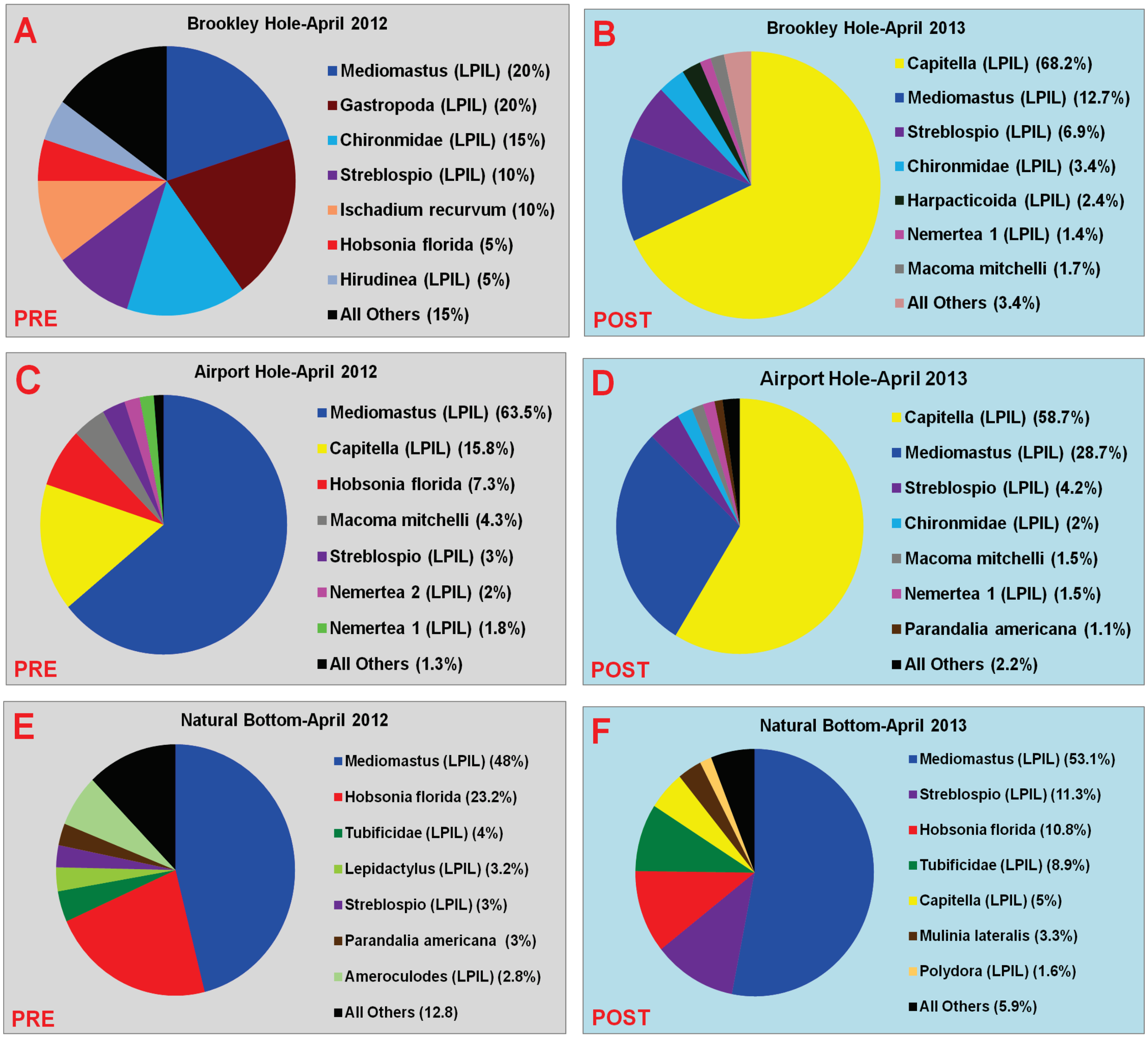
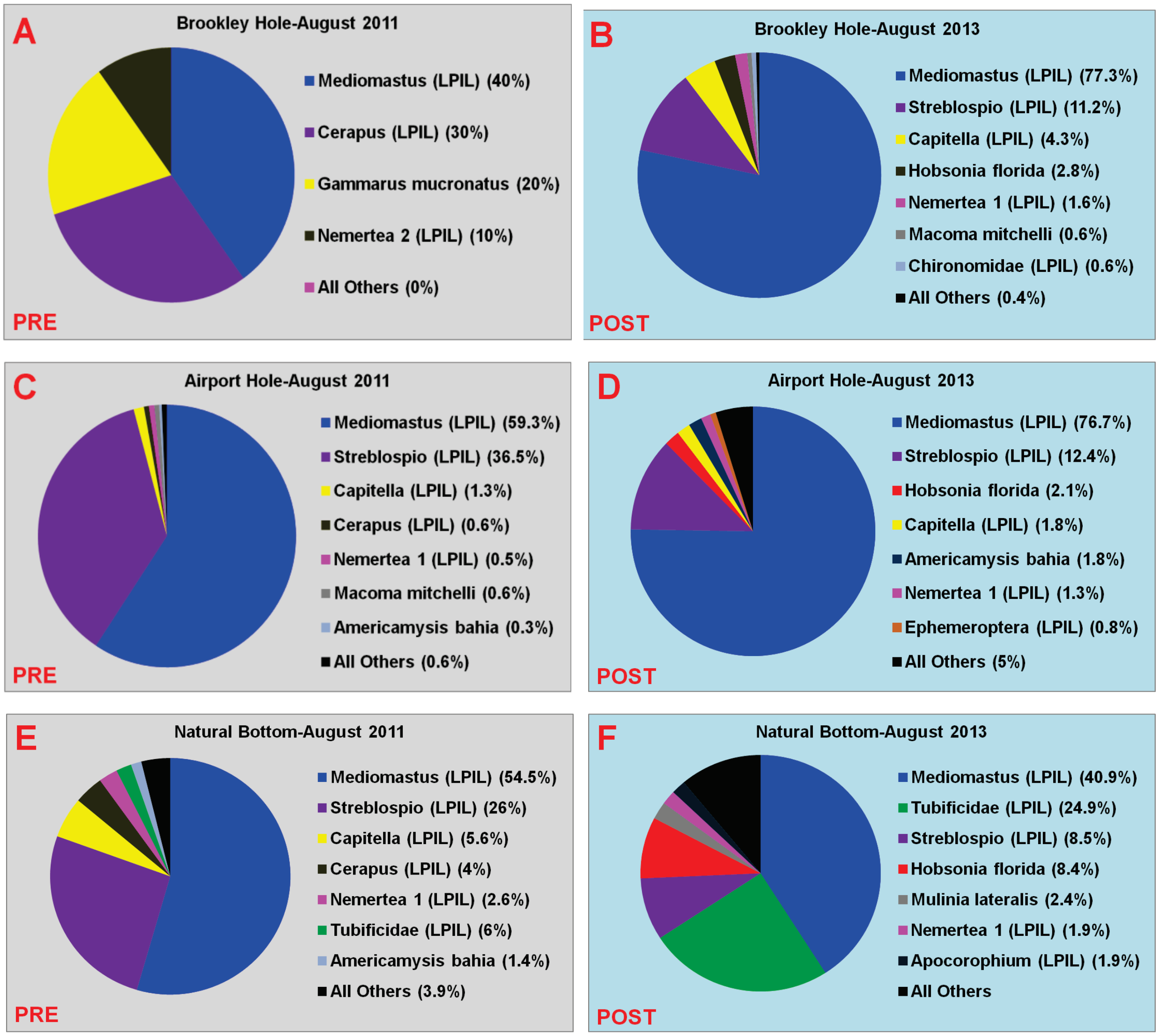


Figure 17. Numerically dominant taxa collected during summer pre- and postsampling at each borrow site and the natural bay bottom. (Note: All graphs on the left side of the figure are prerestoration (April 2012), while graphs on the right side of the figure are postrestoration (April 2013).



Prerestoration (Fall only)

Taxa and species abundance is summarized in Appendix Table 4. Note: there is no postrestoration benthic data for comparison to prerestoration results for the fall sampling; therefore, results are discussed separately from the prerestoration spring and summer results. Fall species assemblages did not differ significantly from spring and summer collections. Polychaetous annelids remained the dominant taxa. *Mediomastus* (LPIL) was most abundant with 45.3% of the total distribution, followed by *Streblospio* at 12.5%. Captellia increased from 5.8% (spring and summer) to 9.1% of the total distribution, while *Hobsonia florida* decreased to less than 1% of the total distribution. The clam *Macoma mitchelli* was the fourth most

abundant taxon and made up nearly 8% of the total abundance. Tubificid oligochaetes were the fifth most abundant taxon (4% of total) and were found principally on the natural bottoms. Two species of Nemertea made up 3.3% and 4% of the total abundance. The amphipods *Cerapus* (LPIL) was not identified in the fall collection, while *Lepidactylus* (LPIL) was found in extremely low numbers (0.09%).

Postrestoration (Spring and Summer)

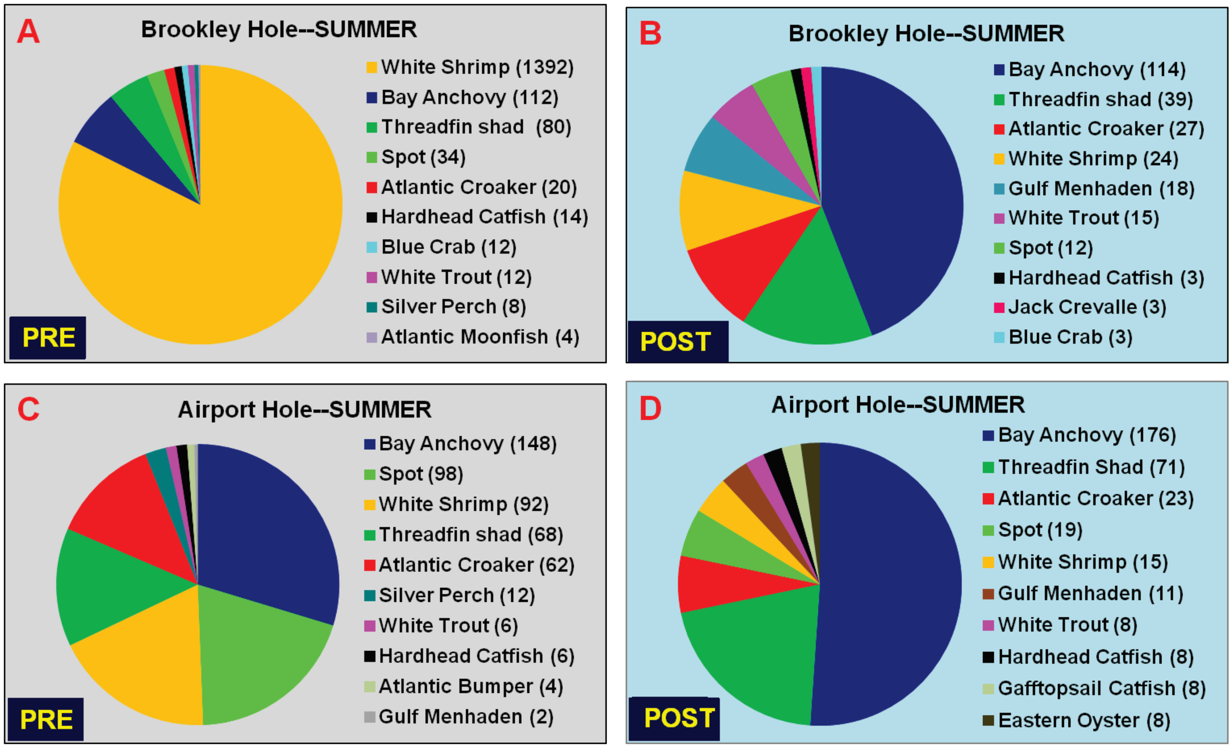
Collections at all three locations and for two seasons (spring and summer 2013) were again heavily dominated by polychaetous annelids. Thirty-seven taxa were identified in postrestoration sampling. Numerically dominant taxa and percent abundance are presented in Figures 16 and 17 and summarized for the entire collection in Appendix Tables 5 and 6. The capitellid *Mediomastus* (LPIL) was the most abundant prerestoration taxon (n = 1,875) overall, comprising 47.7% of all specimens collected (Figure 16 a,c, and e). By site, however, *Capitella* was the dominant taxon at both borrow sites in the spring postrestoration collection (Figure 16b,d), while *Mediomastus* was dominant in the summer pre- and postrestoration collection in both borrow pits and the natural bottom (Figure 17a-f). For both sampling events (spring and summer combined) *Capitella* was the second most abundant taxon, with slightly more than 20% of the total abundance. The lowest numbers of *Capitella* occurred in the natural bottom samples. *Streblospio* was the third most abundant taxon in the postrestoration collection with 9% of the total abundance. Tubificid oligochaetes were the fourth most abundant taxon overall, with 8% of the total abundance; however, oligochaetes were the 2^{nd} most abundant taxa in the natural bottom (Figure 17f). The polychaete *Hobsonia florida* (5.5% of the total abundance) was present in each borrow site, but was predominately found in the natural bottom samples. One species of *Nemertea* accounted for slightly more than 1% of the total abundance. Two species of clams *Macoma mitchelli and Mulinia lateralis* combined for nearly 2% of the total abundance. *Chironomidae* (nonbiting midges) were present at all sites in the postrestoration collection, representing 1.3% of the total abundance. They were absent, however, in the summer prerestoration collection. *Crab megalops* (LPIL), *crab zoea* (LPIL) and *Penaeus setiferus* are a few example taxa found only in postrestoration sampling, while *Nematoda*, *Mytilidae* (LPIL) and *glycinde solitaria* were found only in prerestoration sampling. All were collected in very low abundance. Taxa presence/absence by site and season are summarized in Appendix Table 1.

5 Conventional Fisheries Gear Catch

Summer Catch--Brookley Hole

During prerestoration sampling (August 2011), two of three trawls were conducted in the deepest portion of BH (6.1 m). A total of 15 species, representing 12 species of fish (7 fish families), along with 2 species of crustaceans and 1 species of mollusks, were collected in the postrestoration summer catch in Brookley Hole (Appendix Table 7). Species composition was heavily dominated by white shrimp in the two bottom trawls, although a total of 8 different species were collected. The third trawl was conducted at shallower depths (approximately 3-5 m). White shrimp remained dominant, although abundance was lower in the upper water column when compared to the lower depth strata. CPUE rates were 1,392 shrimp per trawl hour. Other frequent captures in order of numerical abundance included bay anchovy (CPUE = 112), threadfin shad (CPUE = 80), and to a lesser degree spot (CPUE = 34) and Atlantic croaker (CPUE = 20). Species diversity was higher (n = 13) in the shallower water depths. Only white shrimp were caught in appreciable numbers in the lower water column, presumably the result of very low DO concentrations present in the deeper strata of the pit basin that were not conducive to supporting a healthy finfish assemblage. Numerically dominant species and corresponding CPUE rates are presented in Figure 18a. Species composition did not differ dramatically between the pre- and postrestoration catch in Brookley Hole (Figure 18b) White shrimp was replaced by bay anchovies as the numerically dominant species. Bay anchovies (CPUE = 114), along with threadfin shad (CPEU = 39), were caught in relatively high numbers in all three trawls. Other species were found at generally lower abundance, or were found in larger numbers in only one trawl. Considerably lower numbers of threadfin shad and spot, along with two crustaceans, white shrimp, and blue crab during postrestoration sampling were possibly related to low salinity (4 ppt) in Brookley Hole during the summer postrestoration sampling event. Prerestoration salinities ranged from 19 to 21 ppt. Pre- and postrestoration fish assemblage with corresponding CPUE rates are summarized in Appendix Table 8.

Figure 18. Fishery assemblages for the summer catch based on otter trawls in BH and AH.



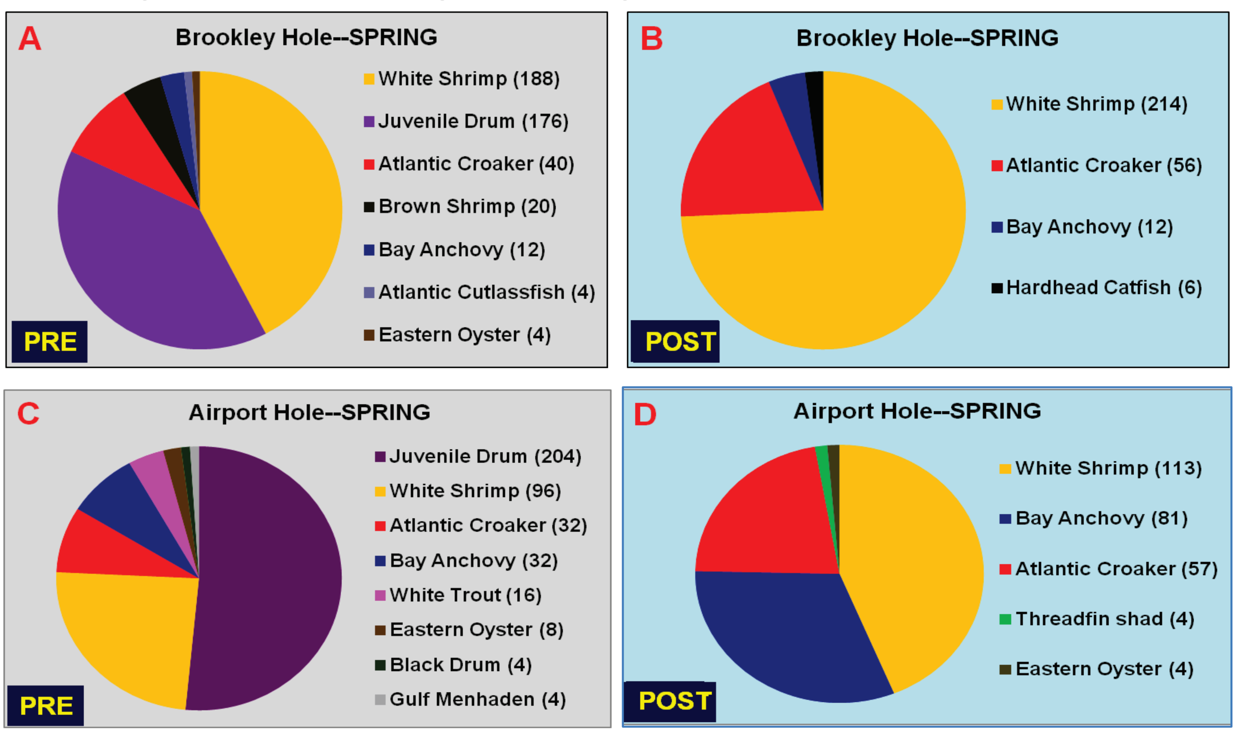
Summer Catch--Airport Hole

Prerestoration species composition was similar among all three trawls during summer sampling. A total of 15 species, representing 12 families, completed the fishery assemblage, including two species of crustaceans, blue crab (*Callinectes sapidus*) and white shrimp, along with one mollusk (squid, *Lolliguncula brevis*). Numerically dominant species, listed in decreasing abundance, included bay anchovy, white shrimp, spot (*Leiostomus xanthurus*), threadfin shad (*Dorosoma petenense*) and Atlantic croaker. The CPUE rates for the top five species in abundance ranged from 60 to 148 fish per trawl hour (Figure 18c). Species diversity was relatively high, with a minimum of 9 species collected in each trawl. The postrestoration summer catch had lower species diversity when compared to the prerestoration catch. Species diversity ranged from 4 to 9 species per trawl. The total number of species collected was ten, with 8 species of fish and 1 each of mollusk and crustacean (Figure 18d). Bay anchovy remained the dominant species, with 176 fish per trawl hour, followed by spot and Atlantic croaker, each with less than 30 fish per trawl hour. Similar to Brookley Hole, salinities were considerably lower during postrestoration sampling (5 ppt) when compared to prerestoration sampling (19 ppt). Lower salinity was potentially a factor in the lower postrestoration species diversity.

Spring Catch--Brookley Hole

White shrimp and juvenile sciaenids were numerically dominant in the spring catch in Brookley Hole, accounting for nearly 83% of the total catch (Figure 19a). Both species had CPUE rates that exceeded 175 fish per trawl hour. The two deeper water (6.1 m) trawls contained a total of 6 different species. One additional trawl was made at shallower depths (3-5 m). Juvenile sciaenids and white shrimp were again present in high numbers when compared to the overall fish assemblage. Unlike the summer catch results, species diversity was similar for both the shallower and deeper water trawls. The similarities between the trawls were likely due to higher dissolved oxygen levels (6 mg/l) measured near bottom during the spring sampling. However, the low salinity measured during spring likely contributed to the lower species diversity for the spring catch when compared to the summer catch. The postrestoration spring catch was dominated by white shrimp (CPUE = 214) and Atlantic croaker (CPUE = 56), which were caught in all trawls (Figure 19b). Juvenile sciaenids, the dominant species in prerestoration sampling, was absent in the postrestoration spring catch. This result was most likely related to cooler than normal water temperatures recorded during the postrestoration sampling. A total of 4 different species were collected from Brookley Hole during postrestoration sampling. Pre- and postrestoration species diversity and CPUE rates are summarized in Appendix Table 8.

Figure 19. Fishery assemblages for the spring catch based on otter trawls in AH and BH.



Spring Catch--Airport Hole

A large number (n = 51) of juvenile sciaenids (juvenile drum LPIL) were caught in all three prerestoration trawls, averaging 204 fish per trawl hour. White shrimp was the second most abundant species in the spring catch (CPUE = 96). Bay anchovy and Atlantic croaker were both present, but in lower numbers than that found during the summer catch, averaging 32 per trawl hour. Species diversity was relatively low, ranging from 5 to 8 species per trawl. When combined, a total of 8 different species, representing 6 fish species (4 fish families) and one each of mollusk and crustacean completed the fisheries assemblages (Appendix Table 9). Low salinities within the pit basin most likely accounted for the low diversity and abundance. The postrestoration catch had a low diversity of only 3 to 4 species per trawl (5 total from all trawls combined). White shrimp, bay anchovies, and Atlantic croaker accounted for 97% of the postrestoration spring catch in Airport Hole. Similar to Brookley Hole, juvenile drum were absent in the post-restoration spring catch. Pre- and postrestoration species diversity and CPUE rates are for Airport Hole and are presented in Figures 19 c,d and summarized in Appendix Table 8. Low salinities and cooler than normal water temperatures are likely primary factors that contributed to the overall decrease in both diversity and abundance.

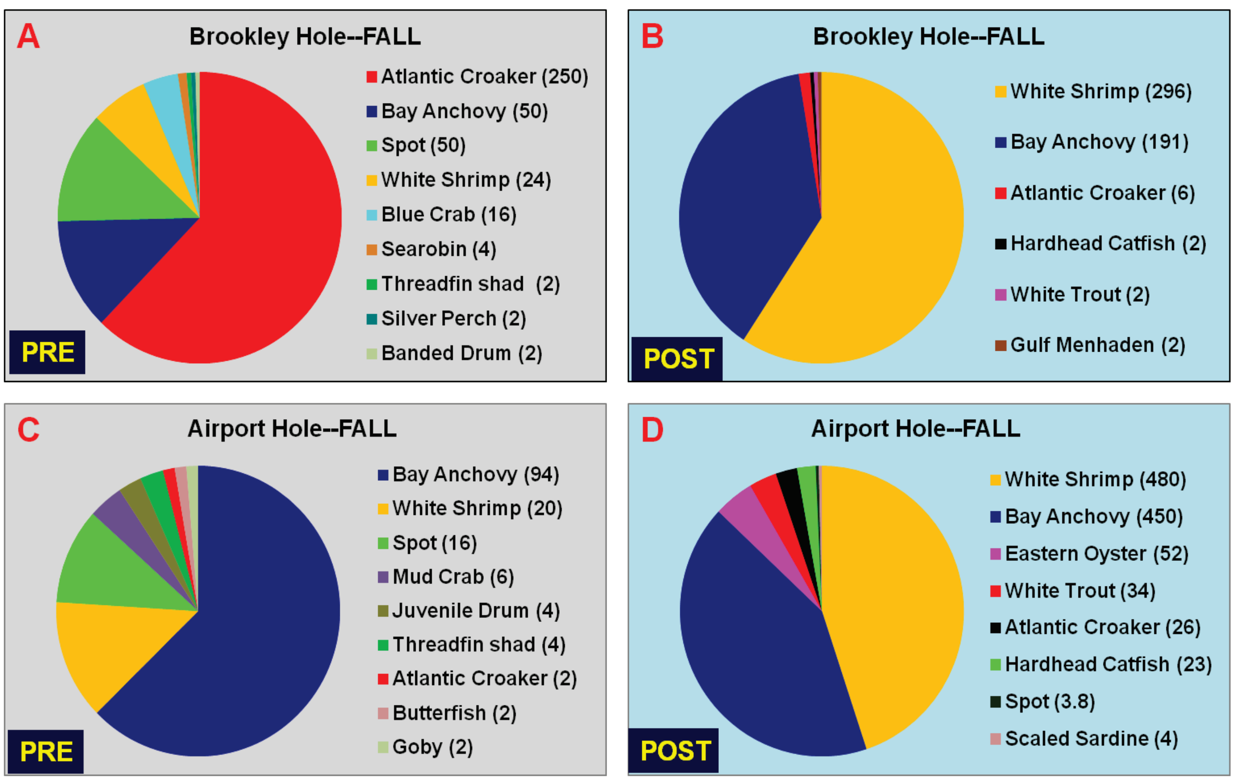
Fall Catch--Brookley Hole

Prerestoration sampling occurred in December 2011. Atlantic croaker (CPUE 250) was the dominant species, accounting for slightly more than 62% of the total catch. Bay anchovy and spot were collected in equal numbers (n = 25, CPUE =50). Two crustaceans, white shrimp and blue crab were collected in moderate numbers (CPUE > 16 and < 30 per trawl/hour). A total of 9 different species completed the fishery assemblage (Figure 19a). Most had CPUE rates of less than 5 fish per trawl hour. Low dissolved oxygen most likely contributed significantly to the low species diversity in the prerestoration fall catch. Postrestoration sampling occurred in October 2012. Given the difference in time periods in which sampling occurred, some difference in the fishery assemblage should be expected. White shrimp (CPUE = 138), followed by Bay anchovy (CPUE = 89), were the dominant species during October 2012 (postrestoration), whereas Atlantic croaker was the dominant species in December 2011 (Prerestoration). A total of 6 different species were collected in the postrestoration fall catch. With the exception of the two dominant species, all had CPUE rates of less than 6 fish per trawl hour (Figure 19b). The species and CPUE rates are summarized Appendix Tables 8.

Fall Catch--Airport Hole

During prerestoration sampling, species composition was similar among all three trawls. Bay anchovy (CPUE = 94) was the dominant species in the prerestoration fall catch (December 2011). Spot and white shrimp were present in moderately high numbers with CPUE rates of 16 and 20 fish per trawl hour. A total of 10 species representing 8 families were collected during prerestoration sampling, including two crustaceans (white shrimp and mud crab) and one mollusk (eastern oyster) (Figure 20c). Ten clusters of the eastern oyster (*Crassostrea virginica*) were brought to the surface during prerestoration trawling. During postrestoration sampling conducted in October 2011, white shrimp and bay anchovy had the highest abundance, both exceeding 120 fish per trawl hour. A total of 8 different species were collected in Airport Hole during postrestoration sampling, included one crustacean and one mollusk. A total of 13 clusters of the eastern oyster were collected during postrestoration sampling. White trout, hardhead catfish and Atlantic croaker were collected in moderately high numbers with CPUE rates of 23 to 34 fish per trawl hour (Figure 20d). Species diversity and CPUE rates for Airport Hole are summarized in Appendix Table 9.

Figure 20. Fishery assemblages for the fall catch based on otter trawls in BH and AH.



6 Fish Size Distribution and Density

Conventional Gear Catch

Total lengths (TL) of collected fishes ranged from 2.2 to 25.5 cm. A summary of fish length by size class for fishes collected from otter trawls in both dredged holes is summarized in Table 3. Fish length distribution by site and season is presented in Figure 21. Combined totals (all seasons, pre- and postrestoration results) and the percentage of the total distribution are presented in Figure 22. Size class categories were fairly evenly distributed between two borrow sites, although slightly greater numbers of fish occurred in the 15-20 cm size class in Brookley Hole when compared to Airport Hole. These larger fish represented 9.3% and 3.2% of the total distribution in Brookley and Airport Holes, respectively. The two largest size classes (20-25 cm and 25-30 cm) had the fewest fish, accounting for only 1% (Airport Hole) and 2% (Brookley Hole) of the total fish assemblage. These size classes were represented primarily by black drum (*Pogonias cromis*) captured in the Airport Hole and cutlassfish (*Trichiurus lepturus*) collected in Brookley Hole. By far, the greatest number of fishes collected fell within the two smaller size (< 5 and 5-10 cm) classes, representing slightly more than 75% of the total distribution within each borrow pit.

Size class distribution of numerically dominant species collected during pre- and postrestoration sampling is summarized in Table 4. After combining results from all seasons and both dredged holes, spot was the largest in terms of mean (mean = 13.8 cm, range = 6.5-19.7 cm) total length of the four numerically dominant fish species. Spot fell within two size classes (10-15 cm and 15-20 cm) during prerestoration and three size classes during postrestoration sampling. Mean fish length (Pre = 19.7 cm TL) decreased by nearly 2 cm TL for spot during postrestoration sampling. Atlantic croaker ranged from 2.5 to 20.1 cm (mean = 11.1 cm), and were present in all size class except 25-30 cm. Peak abundance occurred in the 5-10 cm size class during prerestoration sampling and the 10-15 cm size class during postrestoration sampling. Of the nonfinfish species, white shrimp TL (rostrum tip to telson terminus) ranged from 2 to 13.1 cm (mean = 7.3 cm). Shrimp accounted for 20.7% and 46.5% of the total catch during pre- and postrestoration sampling, respectively. Bay anchovies were the second most abundant species but ranked third in terms of mean fish length for numerically dominant fish species. Mean fish length was 4.5 cm TL

Table 3. Summary of fish length by size class for fishes collected from otter trawls in BH and AH. (Note: fish length data was not available for the summer prerestoration catch. Oyster clusters brought to the surface during trawling are also not included in the table).

Site	Season	Period	Fish Length (cm)						Total
			0-5	5-10	10-15	15-20	20-25	25-30	
BH	Spring	PRE	40	32	31	4	1	2	110
AH	Spring	PRE	71	15	10	1	0	2	99
BH	Fall	PRE	25	59	62	54	0	0	200
AH	Fall	PRE	33	33	7	2	0	0	75
BH	Spring	POST	24	36	6	1	2	4	73
AH	Spring	POST	12	55	69	4	2	1	143
BH	Summer	POST	31	35	11	3	5	0	85
AH	Summer	POST	42	23	21	6	0	0	92
BH	Fall	POST	42	185	3	3	0	1	234
AH	Fall	POST	105	153	3	9	2	0	272
AH Total	All	Combined	263	279	110	22	4	3	681
BH Total	All	Combined	162	347	113	65	8	7	702
Overall Total	All	Combined	425	626	223	87	12	10	1383
% AH	All	Combined	38.6	41.0	16.2	3.2	0.6	0.4	
% BH	All	Combined	23.1	49.4	16.1	9.3	1.1	1.0	
% Overall	All	Combined	30.7	45.3	16.1	6.3	0.9	0.7	

Figure 21. Distribution of fishes by length (TL in cm) captured by 8' shrimp trawl within Brookley and Airport Holes. (Note: Fish length data was not available for the prerestoration summer catch).

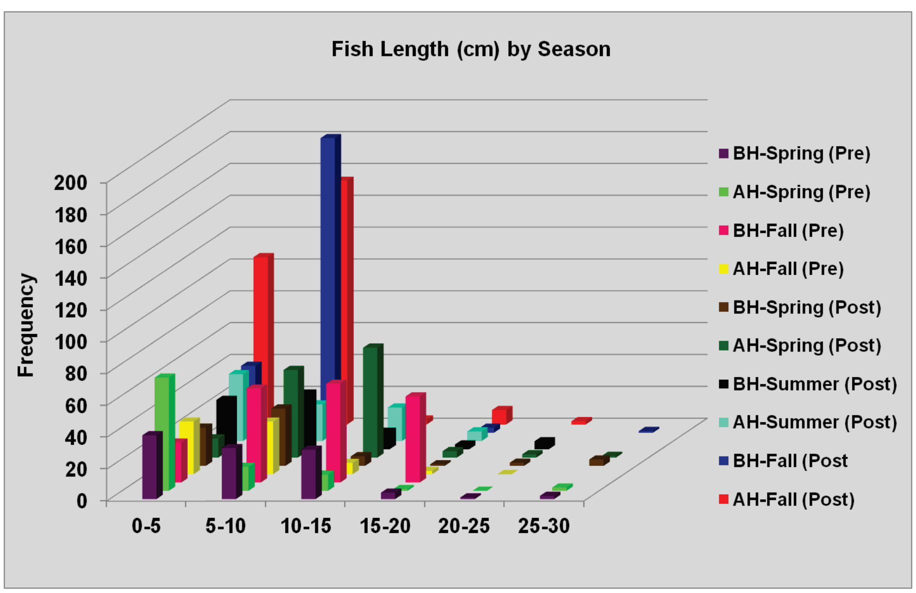


Figure 22. Distribution of fishes by length (TL in cm) combined across seasons in BH and AH. (Note: fish length data not available for prerestoration summer catch.

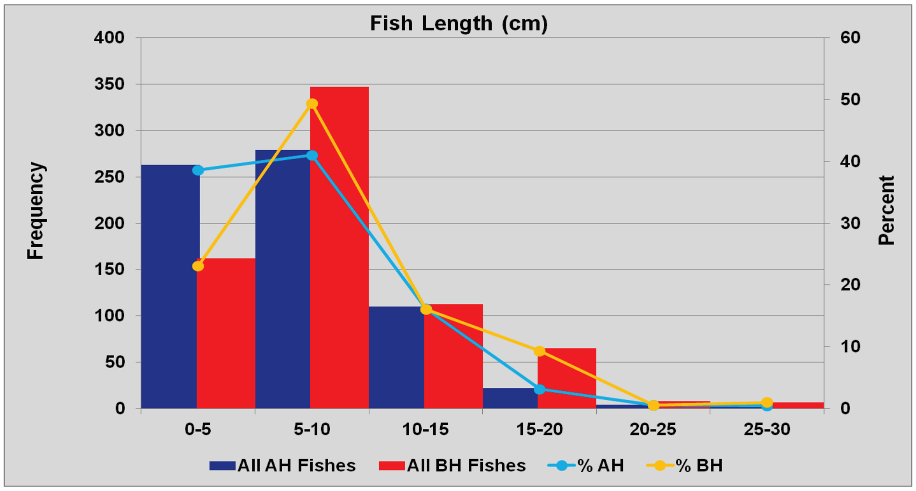


Table 4. Size class distribution of numerically dominant or important species collected by seasonal otter trawls. (All fish sizes are TL in cm.)

Species	Fish Length (cm)			Percent (%)			Size Class Distribution					
Prerestoration	Min	Mean	Max	[1]TD	[2]BH	[3]AH	0-5	5-10	10-15	15-20	20-25	25-30
Atl. Croaker	5.4	11.7	18.3	30.4	93.2	6.8	1	53	49	44	-	-
White Shrimp	2.9	8.8	13.1	20.7	66	34	13	46	41	-	-	-
Juvenile Drum	2.2	3.5	5.5	20.1	45.4	54.6	94	3	-	-	-	-
Bay Anchovy	2.8	4.6	7.6	16.8	71.6	28.4	50	31	-	-	-	
Spot	10	14.6	19.7	6.8	24.2	75.8	-	-	19	14	-	-
Blue Crab	2.4	2.9	3.2	1.7	100	0	8	-	-	-	-	-
White Trout	3.5	4.4	5.0	0.83	0	100	3	1	-	-	-	-
Postrestoration	Fish Length (cm)			Percent (%)			Size Class Distribution					
White Shrimp	2	6.9	12	46.5	39.5	60.5	48	340	27	-	-	-
Bay Anchovy	2	4.6	9.3	36	59.2	40.8	240	81	-	-	-	-
Atl. Croaker	2.5	9.8	20.1	7.5	58.2	41.8	12	17	26	10	1	-
Threadfin Shad	5	6.8	9	3.5	35.5	64.5	-	31	-	-	-	-
White Trout	4.5	7.5	10.5	1.9	35.3	64.7	1	13	3	-	-	
Hardhead Catfish	9.5	14.8	18	1.6	42.9	57.1	-	1	5	8	-	-
Spot	6.5	11.5	18.2	1.2	36.4	63.6	-	4	5	2	-	-
Menhaden	6	8	14.1	1.1	70	30	-	9	1	-	-	-

Legend

[1]Percent of the total distribution for the listed species.

[2]Percent of the listed species present in Brookley Hole compared to Airport Hole.

[3]Percent of the listed species present in Airport hole compared to Brookley Hole.

(range = 2 to 9.8 cm), with the majority (72.1%) occurring in the 0-5 cm TL size class. With the exception of three individuals, all juvenile drum were found in a single size class of 0-5 cm (range = 2.2-5.5 cm, mean = 3.5 cm). In terms of percent of the total catch, white shrimp accounted for 37.2% to the total catch, followed by bay anchovy (29.1%), croaker (15.5%), juvenile

drum (7%), and spot (3.2%). When combined, the four numerically dominant fish species, along with one crustacean (white shrimp), accounted for 92% of the total catch.

Conventional Fisheries Statistics

Ordinations employing nMDS produced an interpretable result (Stress = 0.1), which indicated that there were no differences in species composition between areas or pre- and postrestoration time periods. Hierarchical clustering produced a similar result. Both ordinations are overlaid in Figure 23. This interpretation was further confirmed by PERMANOVA (Table 5). No difference was detected between areas or the pre- and postrestoration time periods. Likewise, there was no significant interaction between these factors. Direct examination of the trawl data either by raw numbers or relative abundance (% of total catch) also supports this conclusion. The most obvious differences occur between sampling dates, but even here reflect only relative changes in the abundance of a few species. The collections are dominated by white shrimp (*Penaeus setiferus*), bay anchovy (*Anchoa mitchilli*), Atlantic croaker (*Micropogonias undulates*), threadfin shad (*Dorosoma petenense*), spot (*Leiostomus xanthurus*), and juvenile sciaendis (in order). The relative abundance of each taxa varies somewhat from one collection to another, but some combination of these taxa comprises the bulk (86-98%) of the catch from each sampling date.

Figure 23. Combined nMDS and Heirarchical clustering results.

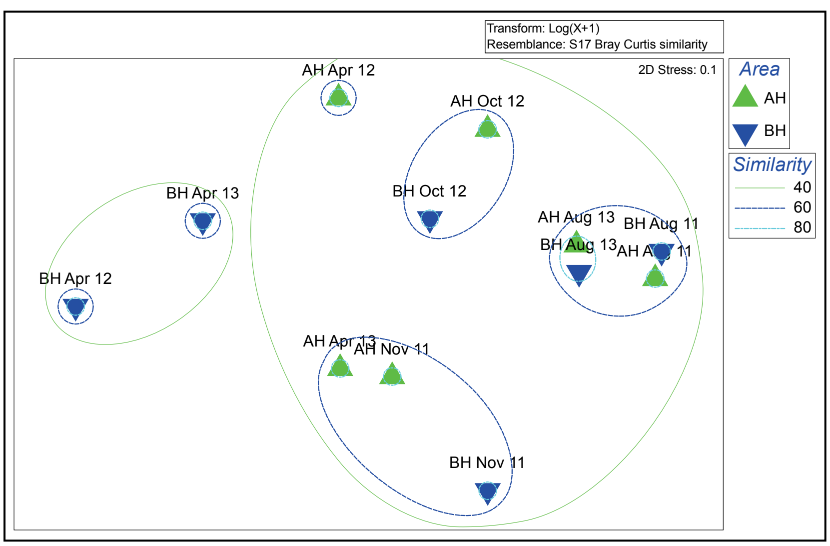


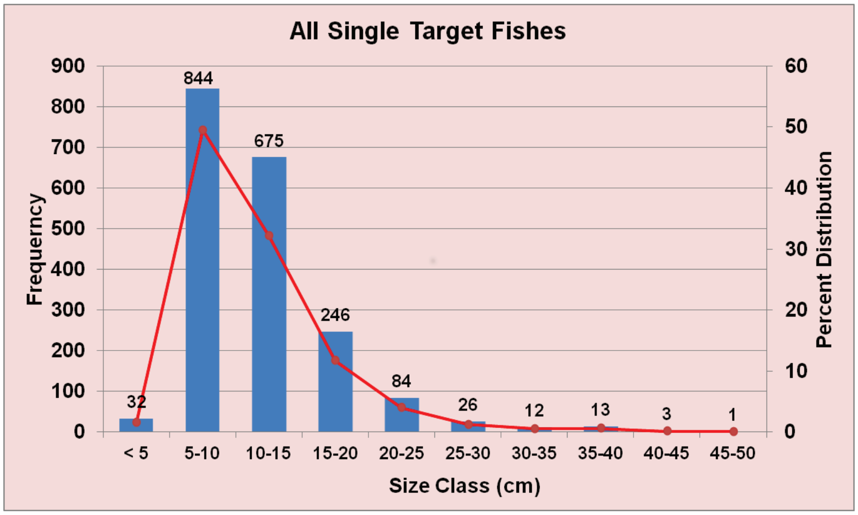
Table 5. PERMANOVA results summary.

Source	df	SS	MS	Pseudo-F	Unique P (perm)	Perms
Area	1	1010	1010	0.60047	0.689	985
Pre-Post	1	932	932	0.55401	0.728	983
ArxPr	1	479	479	0.28487	0.922	991
Residual	8	13456	1682	--	--	--
Total	11	15877	--	--	--	--

Fisheries Hydroacoustics

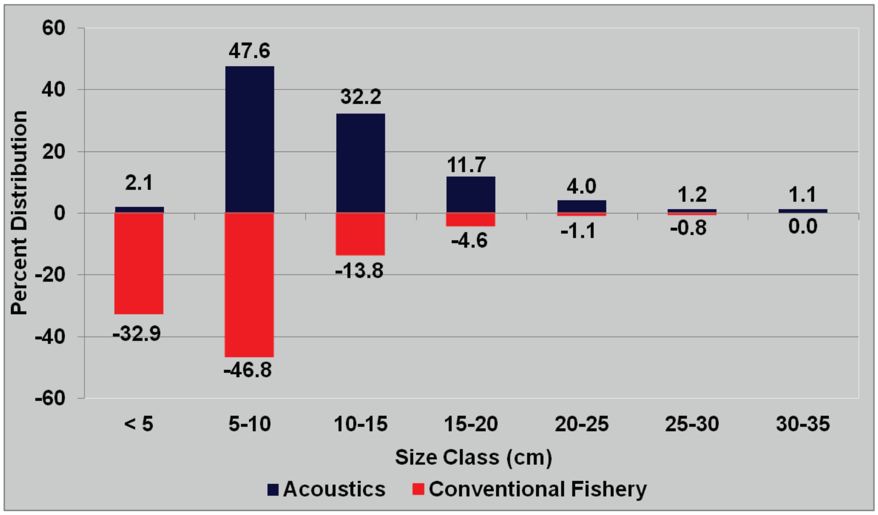
Numbers of acoustically detected fishes and their estimated length by season can be found in Appendix Tables 10 and 11. The frequency distribution by size class for all single target fishes combined during pre- and Year-1 postrestoration sampling are presented in Figure 24. Target strength data were used to calculate estimates of fish length for all acoustically detected and accepted fishes. A total of 2,099 single target fishes were acoustically detected: 1803 (85.9%) were detected in Brookley Hole, while 296 (14.1%) were detected in Airport Hole. Detections are heavily skewed due to the large numbers of white shrimp detected during summer prerestoration surveys. A minimum target strength detection threshold was set at a decibel value of -52.6 dB equivalent to an estimated fish length of 4 cm. As a result, acoustic detections in the lower size class are limited to those whose length range from 4 to 5 cm. The conventional fishery catch indicated a large number of juvenile drum and bay anchovy, along with white shrimp that had lengths from 2 to 4 cm that would not have been included in the total acoustic detections. Estimated lengths of all acoustically detected and accepted single target fishes therefore ranged from 4 to 45.8 cm. Nearly 82% of all acoustic fish detections occurred within two size classes: 5-10 cm (49.5%) and 10-15 cm (32.2%). Frequent captures within these size categories included: spot, Atlantic croaker, bay anchovy, and white shrimp. Slightly greater than 11.7% of all acoustically detected fish fell within the 15-20 cm size class, while 4% fell within the 20-25 cm size class. Atlantic croaker and spot dominated the 15-20 cm size class. Slightly greater than 1% of all acoustic detections occurred in the 25-30 cm size class. Fishes in this size class included black drum and cutlassfish, although detections were few in number. Approximately 1.3% of all acoustically detected fish fell within the four largest size classes raging from 30-50 cm, in 5-cm increments.

Figure 24. Size class and percent total (plotted as red line on 2nd axis) distribution of all single target fishes acoustically detected in Brookley and Airport Holes.



In Figure 25, the length frequency distribution of fishes captured during trawling is compared with that of acoustically estimated target lengths derived from the target strength data. Since much larger numbers of fishes were acoustically detected when compared to totals from the conventional gear, results were converted to a relative frequency percentage by size class. Data were combined for all seasons and both borrow sites. A relatively close correspondence is seen between size frequencies of fishes caught by the conventional and hydroacoustic gears. There may be some evidence of gear selectivity as fishes whose lengths were greater than 30 cm may have avoided capture by conventional sampling; although it should be noted that these upper four size classes combined accounted for only 1.3% of fishes detected acoustically. As mentioned previously, acoustic detections are limited to fishes whose length are 4 cm and greater. As a result, the lower size class is underrepresented when compared to results obtained from conventional fisheries techniques.

Figure 25. Comparison of length-frequency distribution results of fishes in Brookley and Airport Holes based on conventional fishery gears and hydroacoustic measurements.



7 Fish Density

Prerestoration

Fish densities (fish/100m^3) were determined by echo-integration by site, season, and survey transect and are summarized in Appendix Tables 10 and 11. At Brookley Hole, fish density was also determined for fishes both above and below the 4-m depth stratum, a midwater point where DO (mg/l) concentrations, particularly during spring and summer (and to a slightly lesser degree fall), are at hypoxic/anoxic levels, or to where salinity stratification was most pronounced. Note that at Airport Hole, with the exception of high tide, water depths rarely exceed 4 m. The highest estimated fish density was 60.4 fish/100 m^3 during summer sampling at Brookley Hole. The majority of fish targets tended to avoid the lower portion (> 4 m) of the water column during summer in the central, deeper portion of the basin. This is clearly illustrated in the example fisheries echogram presented in Figure 26. When fish targets were present nearer the bottom, it was typically along transects occupied at the northern or southern basin perimeter where total water depth was less than 4 m. When partitioning Brookley Hole Basin into upper (< 4 m) and lower (> 4 m) depth strata, fish densities in the upper water column (73.6 fish/100 m^3) more than doubled that of the lower (density = 34.1 fish/100 m^3) water column during summer sampling. Based upon conventional gear catch, lower water column (> 3 m) density represented by the presence of white shrimp had few if any finfish. During spring, fish density in the lower water column (mean = 23.3 fish/100 m^3) was nearly three times greater than fish density in the upper water column (8.4 fish/100 m3). The same pattern was found in the fall when lower water column fish density (mean = 18.8 fish/100 m^3) was nearly five times that of the upper water column (3.9 fish/100 m^3). Again white shrimp contributed significantly to density estimates within the lower water column. Regardless of season, fish targets still tended to avoid the lower depth strata, particularity within 1 to 2 meters of the central basin bottom in Brookley Hole, likely attributable to lower DO concentrations. Fish density (mean = 60.4 fish/100 m^3) during the summer sampling event in Brookley Hole exceeded average densities during both spring (mean = 11.4 fish/100 m^3) and fall (mean = 8.2 fish/100 m^3) at Brookley Hole, as well as for all three prerestoration seasonal surveys at Airport Hole (Figure 27). Corresponding seasonal densities at Airport Hole were highest in fall (mean = 29.9 fish/100 m^3), followed by spring (mean = 18.7 fish/100 m^3) and

summer (mean = 13.2 fish/100 m^3). In two of the three seasonal surveys (spring and fall), total fish density at Airport Hole exceeded that of Brookley Hole (Figure 28).

Figure 26. Example fisheries echogram taken during summer prerestoration sampling at Brookley Hole.

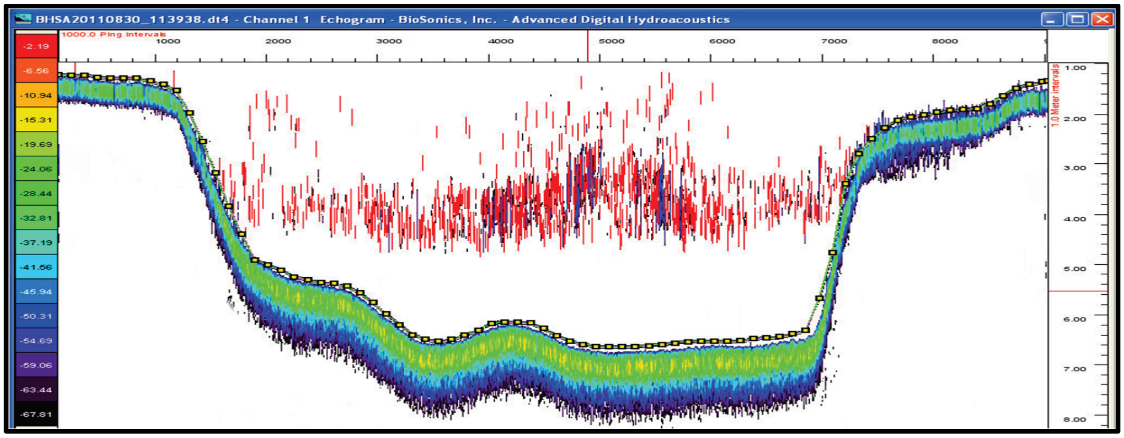


Figure 27. Total fish density (fish/100 m3) by season for Brookley Hole.

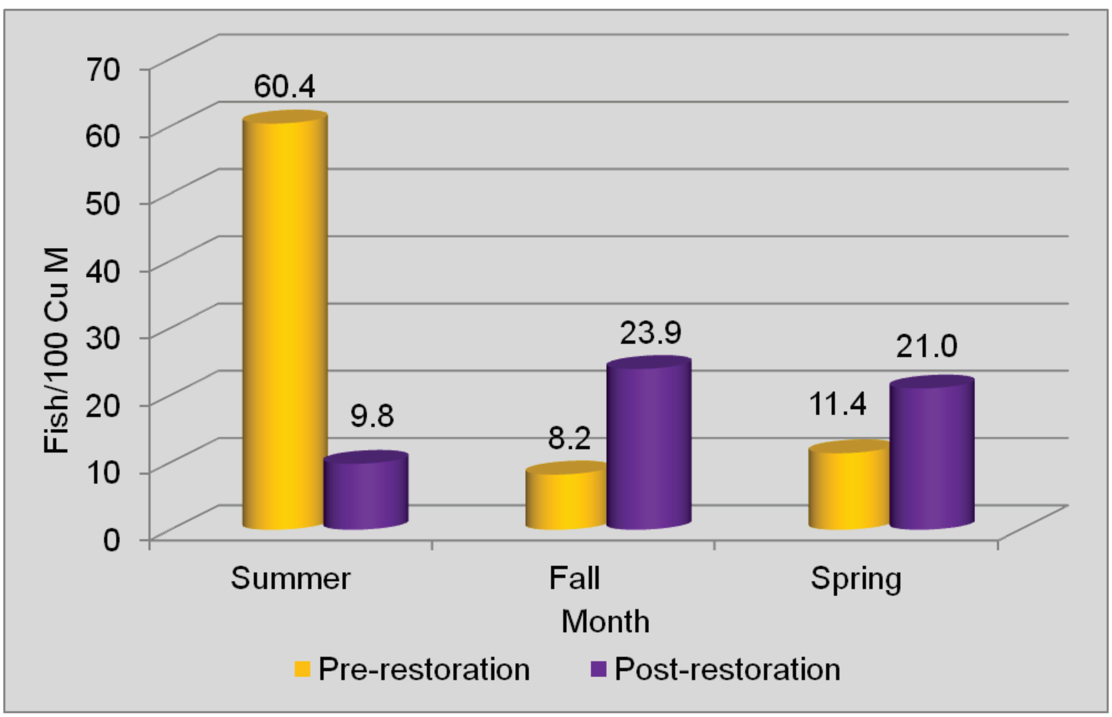
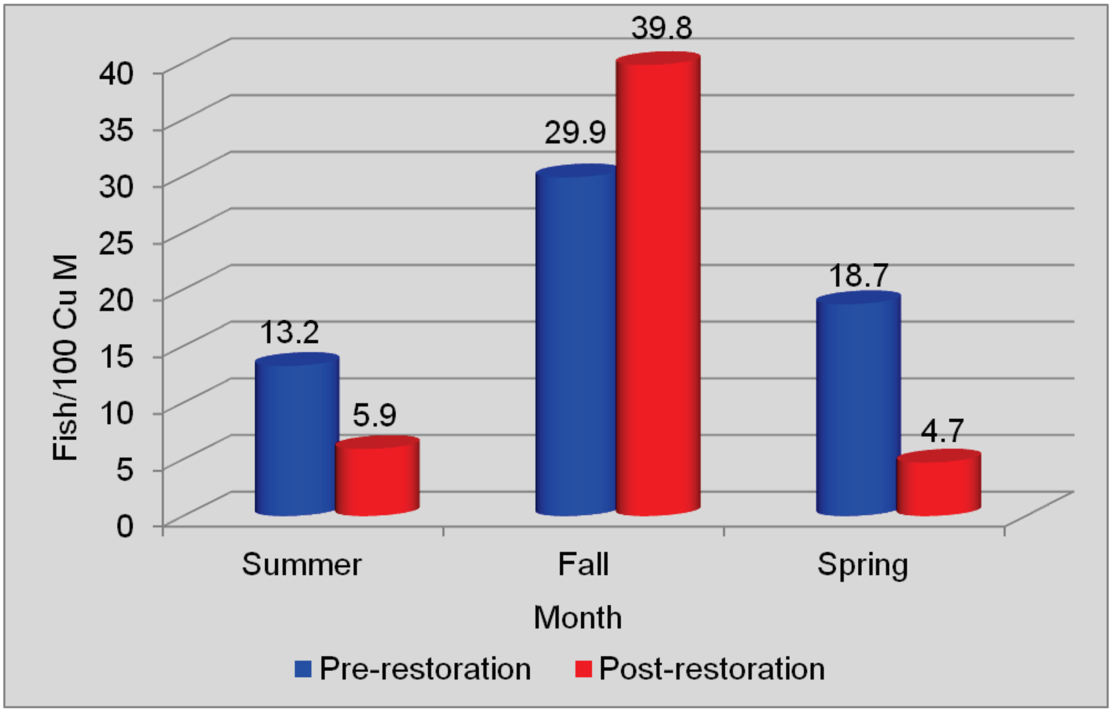


Figure 28. Total fish density by season for Airport Hole.



Fish densities in Brookley Hole peaked in the central reach of the borrow pit basin during summer (171 fish/100 m^3) and fall (41 fish/100 m^3). In spring, peak densities (21 fish/100 m^3) occurred at the northern perimeter of the Brookley Hole basin. At Airport Hole, peak densities occurred at the southern perimeter of the pit basin in summer (21 fish/100 m^3), and in the central and north-central portion of the pit basin during both fall (313 fish/100 m^3) and spring (49 fish 100 m^3), respectively. During fall sampling, higher fish densities were attributed to one large school of fish located along Transect #5 in the central portion of the pit basin where fish density exceeded 300 fish/100 m^3. With the exception of this one transect, all others occupied in the central portion of the Airport Hole Basin had substantially lower fish densities. With the exception of the summer sampling in BH and the fall sampling in AH, where along transect densities peaks were disproportionally high compared to other transects occupied across the basin, fish densities tended to be more uniformly distributed among transects.

Vertical distribution of acoustically detected single fish targets indicated a general trend in avoiding the lower two meters of the water column in Brookley Hole. For example, in the central deepest portion of the Brookley Hole pit basin, average fish depth was 4.2 m (maximum = 5.8 m) below surface in 6.7 m total water, or 1.6 (maximum) to 2.5 m (average) off the

basin bottom during spring sampling. In Airport Hole, fish tended to avoid only the lower 0.3 to 0.6 m of the pit basin. Average and maximum target depths and average and maximum pit depth are summarized in Appendix Tables 10 and 11.

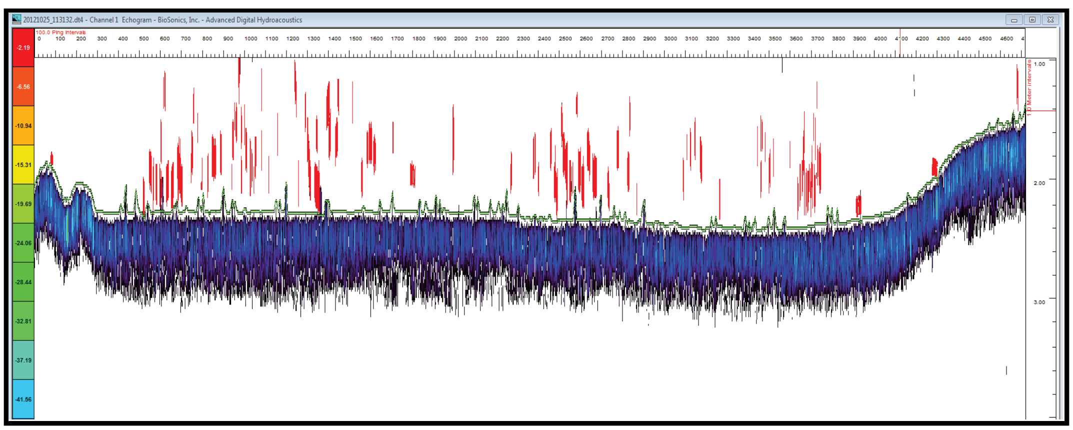
Numbers of fish and shellfish based on echo-integration for each season and site are summarized in Appendix Tables 10 and 11. Estimated totals peaked at 7,788 during summer sampling in Brookley Hole, compared to only 270 at Airport Hole. Spring sampling produced similar results. Based on the conventional gear catch in Brookley Hole, a significant portion of the overall estimated number of targets are likely attributed to the presence of large numbers of white shrimp. CPUE rates for white shrimp average 1,382 shrimp per trawl hour, compared to only 92 shrimp per trawl hour in Airport Hole. Estimated numbers of fish were closer in value for both dredged holes (BH = 4,257 fish/shellfsih, AH = 3,248 fish/shellfish) during the late fall sampling, differing by approximately 1,000 fish/shellfish. The percentage of white shrimp found in both dredge holes during this sampling event was fairly low.

Postrestoration

Postrestoration fish and shellfish densities per 100 m^3 by site, season, and survey transect and are summarized in Appendix Tables 10 and 11. Total densities by season for Brookley and Airport Holes are presented in Figures 27 and 28. Density during the summer sampling was considerably lower (9.8 fish/shellfish/100 m^3) than prerestoration densities, given a significant decrease in the number of white shrimp based on the conventional gear catch. Although finfish species avoided the portion of the pit basin beyond midwater depths, a large number of white shrimp were collected in the lower water column. This avoidance zone to finfish species, however, did contribute to the overall prerestoration density based solely on the presence of white shrimp. This area was eliminated during postrestoration sampling having been filled with dredged sediment taken from the nearby navigation channel. As a result, summer density estimates were lower during postrestoration monitoring. While a contributing factor to the lower density estimate during summer sampling, this does not completely account for the lower overall density. When put into context with summer density estimates from Airport Hole, which fell from 13.2 fish/shellfish/100 m^3 (prerestoration) to 5.9 fish/shellfish/100 m^3 (postrestoration), a decrease of 55%, the lower summer density estimates observed in Brookley and Airport Hole may simply be normal variation on a yearly basis. Year 2 postrestoration monitoring may help to confirm this theory.

Fish density estimates increased during postrestoration in Brookley Hole during both the spring and fall sampling. Spring estimates increased nearly 50% from 11.4 targets/100 m^3 to 21 targets/100 m^3. During fall, density increased by nearly a factor of four from 8.2- to 23.9- fish/shellfish/100 m^3. An example fisheries echogram taken in Brookley Hole during fall sampling showing fish utilizing the entire pit basin is presented in Figure 29. In Airport Hole, fish density decreased during spring sampling (density increased at BH) by a factor of four from 18.7- to 4.7 fish/shellfish/100 m^3, resulting from low DO in the lower portion of the borrow pit, a condition eliminated in Brookley Hole postrestoration. Fish/shellfish density did increase slightly during the fall sampling from 29.9- to 39.8 from pre- to postrestoration. Water quality is typically less a factor during fall in Airport Hole. The highest along transect (175 fish/shellfish/100 m^3) density occurred in the central portion of the pit basin during fall sampling. The lowest along transect density also occurred in Airport Hole at only 7 fish/shellfish/100 m^3 in the northern portion of the pit basin during spring sampling. In Brookley Hole, areas with peak densities varied between seasons occupying the southern portion of the pit basin during summer, the northern portion during fall, and the central portion during spring.

Figure 29. Example fisheries echogram taken during postrestoration sampling of Brookley Hole.



Numbers of fish and shellfish were estimated by echo-integration. Two schools of fish detected in Airport Hole during fall produced estimates of 2,605 fish/shellfish, substantially higher when compared to Brookley Hole (570 fish/shellfish). Differences were not a large during the other two seasons sampled. Higher numbers of fish were estimated for Brookley Hole during spring (n = 457) when compared to Airport Hole (n = 229). During summer, Airport had a higher total of estimated fish/shellfish (n = 673) when compared to Brookley Hole (n = 385).

8 Conclusions

Studies were conducted at two dredged holes in upper Mobile Bay, Alabama to investigate the feasibility of restoring fishery resource habitat using dredged material. Restoration consists of the partial filling to date of Brookley Hole to midwater depths. Both dredged holes were successfully characterized in terms of water quality, sediment grain size composition, benthic invertebrate community assemblage and structure, fishery assemblage composition and fishery utilization patterns.

During the course of surveys undertaken during the prerestoration study, there was evidence of periodic water column stratification that induced hypoxic and/or anoxic water quality conditions. Hypoxic/anoxic conditions were most severe during summer and least severe during fall. During fall, lowest DO readings were slightly below 3 mg/l. During both fall and summer, DO fell to near zero mg/l, particularity in the lower 1-m of the water column. Hypoxic (< 3 mg/L) conditions were present during spring and summer at depths > 3 m and during fall at depths greater than 4 m. Therefore, conditions were not suitable to sustain a healthy finfish assemblage in the lower water column of Brookley Hole prior to restoration.

Hypoxic conditions (DO < 3 mg/l) were present during conventional fisheries sampling during summer and fall; however, not for spring (Bottom DO =5 mg/l). One explanation for this is that acoustic fisheries surveys conducted by ERDC occurred on 4 April during relatively calm conditions. Shortly thereafter, stormy conditions delayed conventional sampling until 13 April. Wind-driven waves may have mixed the water column leading to higher DO concentrations during sampling on 13 April. During postrestoration sampling, DO concentrations did not fall below 6 mg/l during any seasonal survey.

Salinity stratification was clearly evident in Brookley Hole during both spring and fall sampling events. During spring, salinity readings were as low as 2 ppt in the upper water strata, before increasing sharply to 11 ppt. In fall, salinity rose from 5 ppt in surface waters to greater than 20 ppt at the 3-m depth stratum. In postrestoration surveys, salinity stratification was only present during the spring sampling event in Brookley Hole. In Airport Hole, salinity stratification was most prominent during fall

prerestoration and spring postrestoration sampling. Low salinities typically coincided with low species diversity and abundance.

Prerestoration results of the infaunal sampling indicate that both dredged holes supported impoverished benthic assemblages comprised largely of opportunistic, disturbance-adapted infauna. The structure of the benthic communities differed significantly between Airport and Brookley Holes, and between the dredged holes and the natural bay bottom. Average taxa per sample were extremely low, during both summer and spring prerestoration sampling in Brookley Hole. Average number of taxa and abundance increased significantly during postrestoration sampling. Average taxa in Airport Hole during spring sampling was similar to that of Brookley Hole, indicating that periodic low DO concentrations even in the shallower basin can have dramatically negative effect on the benthic assemblage. During the spring sampling in Airport Hole, there was no evidence of hypoxia. The average number of taxa was similar to results obtained from postrestoration sampling in Brookley Hole. Average number of taxa and average numbers of animals per sample were still considerably lower than those from natural bottom samples. There was little difference in the number of taxa from samples taken in the natural bottom around the periphery of each dredged hole.

Vittor & Associates (1982) reported that the number of infaunal taxa varied from 9 to 19 per sample, just off the southeastern edge of Pinto Island, located to the northwest of Brookley Hole. By season, taxa richness was greatest in fall (December) in the natural bay bottom near both holes (total taxa at AN = 20 and BN = 22), followed by 13 (BH) to 20 (AH) in summer and 17 (BH) to 18 (AH) in spring. The lowest values (13-14) occurred in summer 2011 in the current study. These values were consistent with those reported by Vittor and Associates (1982). A separate study conducted by the Alabama Coastal Area Board (ACAB, 1981) near Pinto Island indicated a lack of consistency in seasonal abundances. The authors reported species richness (total number of taxa) was lowest in the late spring and summer and highest during the winter months. Lowest taxa richness in the current study was during the summer at both dredged holes, as well as at the reference sites. Numerically dominant taxa included several taxa of polychaetes, including *Mediomastus* (LPIL), *Streblospio* (LPIL), *Capitella* (LPIL), and *Glycinde solitaria*. These results were consistent with a study conducted by Vittor (1979).

The same trend was observed for macroinvertebrate density. Densities in the current study were within the ranges reported by Vittor and Associates, Inc., (1982) in a study of benthic macrofauna off the southeastern edge of Pinto Island. However, in Brookley Hole, densities were well below densities (most notably during prerestoration) obtained from natural bottom samples in the current study and those reported by Vittor and Associates (1982). When combining pre- and postrestoration results, densities increased from 942 animals per/m^2 in Brookley Hole, to 2,434 animals per/m^2 in Airport Hole, a difference of 1,493 animals per/m^2. When combining both natural bottom sites (pre and post), density (4,036 animals/m^2) exceeded Airport Hole density by 1,600 animals/m^2 and by nearly 3,100 animals per/m^2 when compared to Brookley Hole. Excluding the very low densities associated with the prerestoration condition of Brookley Hole, densities in Airport Hole and the natural bottom would still exceed Brookley Hole by 987 to 2,966 animals per/m^2.

Based on the average and total number of taxa per sample, average and total number of animals per sample and overall density, two alternative conclusions can be made with regards to the present condition of Brookley Hole. Either Brookley Hole has not fully recovered in terms of benthic assemblage, or both dredged holes are still sufficiently deep relative to the natural bay bottom to recover, to a similar benthic condition found in the natural bay bottom. Both holes remain candidates for further placement of dredged sediment in order to restore historical bathymetry.

The results of conventional and acoustic fisheries sampling indicated that both borrow pits were seasonally occupied by fishery resource assemblages typical of greater Mobile Bay. Species composition included several taxa that exemplify coastal pelagic and demersal fishes, as well as commercially important shellfish. Several pelagic forage fishes were present in each dredged hole. Bay anchovies and threadfin shad were captured in moderate numbers, reflecting their typical occurrences in schools. Their presence may be an indication that mobile midwater fishes may move into and out of the holes on a frequent basis as part of movements on larger spatial scales rather than an affinity for “deep” habitat. Striped anchovies and Gulf menhaden were captured in low numbers during prerestoration sampling. CPUE rates increased in both dredged holes during postrestoration sampling. Demersal fishes were definitely present in both holes, as indicated by catches of Atlantic croaker and spot. Both species have recreational and commercial value. Atlantic croaker, juvenile drum, bay

anchovy, and spot comprised the majority of fishes captured during prerestoration. Bay anchovy, Atlantic croaker, threadfin shad and white trout comprised the majority of fishes captured during postrestoration. White trout (prerestoration) and spot (postrestoration) was the fifth most abundant of the finfish species.

At Brookley Hole, Atlantic croaker was dominant, in both the pre- and postrestoration catches, followed by bay anchovy. With the absence of juvenile drum and low numbers of spot in the postrestoration collection in Brookley Hole, threadfin shad was the third most dominant species. In prerestoration sampling, juvenile drum was the third most abundant species, followed by spot and threadfin shad. At Airport Hole, bay anchovies were prominent in both pre- and postrestoration sampling, followed by Atlantic croaker and threadfin shad. In prerestoration sampling, bay anchovies were prominent followed by spot, juvenile drum, Atlantic croaker, and threadfin shad. Species composition did not vary significantly between borrow sites or during the pre- and postrestoration time periods.

Commercially important shellfish taken at both sites include brown and white shrimp, eastern oyster, and blue crab. In terms of the entire fishery assemblages, white shrimp was the numerically dominant species captured in Brookley Hole and the second most abundant species captured at Airport Hole. Although brown shrimp were present at both sites, they were taken in far fewer numbers. Oyster "clumps" were most numerous in Airport Hole, but these were most likely incidental captures taken along the rim or upper side slopes of the basin. Blue crabs were present at both sites but in low numbers. Fishes were observed to move freely within and outside of both borrow pits. The "flux" of fishes between the holes and adjacent shallow habitats may be influenced by proximity of both dredged holes to shorelines, and the lack of strong tidal flows. Inspection of individual echograms of transects across the dredged holes yielded some evidence of association between fish targets and bathymetric features, such as the toes or upper rims of the side slopes of the holes. It should be noted that fisheries acoustics techniques provide data on fishes in the water column only and not in contact with the substrate. Therefore, fish densities estimated acoustically herein do not include flatfishes, gobies, and other bottom-oriented species.

There was strong evidence of fish avoiding the lower depth strata in Brookley Hole, particularity during summer and, to a lesser degree, during

spring, prerestoration. In summer, the avoidance zone typically spanned from midwater to bottom of the pit basin, particularly in the central deeper portion of the pit basin. In spring, the avoidance zone was generally limited to the lower 1 to 1 ½ m of the water column. This area was shown to be persistently hypoxic in Brookley Hole. Depth distribution of fishes was shown to change subtly between seasons and regions of the basin. The latter observation may simply reflect differences in geometry and bathymetry of the dredged holes and orientations to prevailing currents. Fishes were more evenly distributed throughout the water column in both dredged holes in the spring survey, but congregated at mid-water depths during summer in Brookley Hole. At Airport Hole, fishes tended to favor the lower depth strata during summer, but were more evenly distributed throughout the water column during spring.

Brookley Hole remains a suitable candidate for either partial or complete filling with dredged material. Partial filling, as discussed in the current paper, resulted in a significant increase in benthic diversity and abundance, although results are still below natural bay bottom levels. Brookley Hole remains a candidate for consideration to full restoration to the natural bay bathymetry. A similar conclusion can be made for Airport Hole. At Airport Hole, benthic density levels fall well below that of the natural bay bottom. In addition, during times of low DO concentrations, as observed during the summer sampling event, the benthic assemblage at Airport Hole can fall to levels similar to that of the prerestoration condition of Brookley Hole. From an ecological perspective, the partial or complete filling of these dredged holes would benefit fishery resources through elimination of hypoxic/anoxic zones common to these bathymetric features. Partial filling would restore the degraded habitat, while not negatively impacting the upper portion of the water column utilized by a variety of fish and shellfish species. Complete filling would restore historical bathymetric contours to that area of upper Mobile Bay. Other long-term restoration endpoints might be considered, such as establishment of submerged aquatic vegetation, oyster reef, or benthic habitats that support fishery resources.

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Appendix A: Species Assemblage of Benthic Invertebrates and Finfish

Appendix Table 1. Summary of presence/absence of invertebrate species Note: The following species were found in only one season and one location: Hesionidae (LPIL), prerestoration, all others were collected during postrestoration sampling to include: Cladocera (LPIL), Copepoda (LPIL), Crab megalops (LPIL), Crab Zoea (LPIL), Myrophis punctatus, Mysidacea (LPIL), and Penaeus setiferus. *prerestoration.

	AH	AN	BH	BN	AH	AN	BH	BN	AH	AN	BH	BN	AH	AN	BH	AH	AN	BH	BN
	*August 2011				*December 2011				*April 2012				April 2013			August 2013			
Americamysis bahia	X	X		X					X		X	X				X	X	X	X
Ameroculodes (LPIL)						X		X		X		X	X	X		X	X	X	X
Apocorophium (LPIL)		X		X		X	X	X						X			X		X
Callinectes sapidus						X						X					X		
Capitella (LPIL)	X	X		X	X	X		X	X	X			X	X	X	X	X	X	X
Cerapus (LPIL)	X		X	X								X					X		X
Chironomidae (LPIL)						X			X	X	X		X	X	X	X	X	X	X
Copepod X (LPIL)	X	X																	
Cumacea (LPIL)						X				X				X	X				
Edotea triloba		X		X				X		X	X		X	X			X		X
Ephemeroptera (LPIL)																X		X	
Gammarus mucronatus			X		X			X				X				X			X
Gastropoda (LPIL)									X	X	X					X	X		
Glycinde solitaria					X	X	X	X											
Grandidierella bonneroides						X		X		X				X			X		X
Hargeria rapax											X		X		X				
Harpacticoida (LPIL)					X			X		X			X		X				
Hirudinea (LPIL)							X			X	X	X							
Hobsonia florida					X	X		X	X	X	X		X	X	X	X	X	X	X
Hypereteone heteropoda						X						X							
Ischadium recurvum											X								X
Laeonereis culveri		X											X		X				
Lepidactylus (LPIL)						X				X		X					X		

	AH	AN	BH	BN	AH	AN	BH	BN	AH	AN	BH	BN	AH	AN	BH	AH	AN	BH	BN
	*August 2011				*December 2011				*April 2012				April 2013			August 2013			
Macoma mitchelli	X				X	X	X	X	X	X		X	X	X	X	X		X	
Mediomastus (LPIL)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mulinia lateralis		X				X		X	3	X			X	X		X	X	X	X
Mytilidae (LPIL)					X														
Nematoda (LPIL)	X				X	X	X												
Nematoda (LPIL)												X		X					
Nemertea 1 (LPIL)	X	X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Nemertea 2 (LPIL)			X	X	X	X		X	X	X			X						X
Nereis succinea		X		X	X	X		X									X		X
Ostracoda (LPIL)								X						X					
Parandalia americana		X		X		X		X		X		X	X	X	X			X	X
Paraprionospio pinnata							X		X										
Polydora (LPIL)		X		X		X		X						X					X
Polydora cornuta										X		X							
Streblospio (LPIL)	X	X		X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Tubificidae (LPIL)		X		X		X		X	X	X		X	X	X	X	X	X		X

Appendix Table 2. Summary of benthic abundance by species in numerical order for the Summer (August 2011) prerestoration collection.

	Airport Hole		Brookley Hole		Airport-Natural		Brookley-Natural		Seasonal	Seasonal
Taxa	Total	% AH	Total	% BH	Total	% AN	Total	% BH	Total	Distribution
Mediomastus (LPIL)	185	59.3	4	40	314	62.2	262	47.5	765	55.5
Streblospio (LPIL)	114	36.5	-	-	109	21.6	166	30.1	389	28.2
Capitella (LPIL)	4	1.3	-	-	33	6.5	26	4.7	63	4.6
Cerapus (LPIL)	2	0.6	3	30	-	-	42	7.6	47	3.4
Nemertea 1 (LPIL)	2	0.6	-	-	12	2.4	15	2.7	29	2.1
Tubificidae (LPIL)	-	-	-	-	9	1.8	13	2.4	22	1.6
Americamysis bahia	1	0.3	-	-	6	1.2	9	1.6	16	1.2
Polydora (LPIL)	-	-	-	-	6	1.2	7	1.3	13	0.9
Parandalia americana	-	-	-	-	4	0.8	7	1.3	11	0.8
Nereis succinea	-	-	-	-	4	0.8	2	0.4	6	0.4
Apocorophium (LPIL)	-	-	-	-	2	0.4	1	0.2	3	0.2
Copepod X (LPIL)	1	0.3	-	-	1	0.2	-	-	2	0.2
Edotea triloba	-	-	-	-	1	0.2	1	0.2	2	0.2
Gammarus mucronatus	-	-	2	20	-	-	-	-	2	0.2
Laeonereis culveri	-	-	-	-	2	0.4	-	-	2	0.2
Macoma mitchelli	2	0.6	-	-	-	-	-	-	2	0.2
Mulinia lateralis	-	-	-	-	2	0.4	-	-	2	0.2
Nemertea 2 (LPIL)	-	-	1	10	-	-	1	0.2	2	0.2
Nematoda (LPIL)	1	0.3		-	-	-	-	-	1	0.1
Total Animals	312	-	10	-	505	-	552	-	1379	-
Average. # Animals	62	-	2	-	168	-	184	-	-	-
Total # Taxa	9	-	4	-	14	-	13	-	-	-
Average # Taxa	1.8	-	0.8	-	10	-	9	-	-	-

Appendix Table 3. Summary of benthic abundance by species in numerical order for the Spring (April 2012) prerestoration collection.

	Airport Hole		Brookley Hole		Airport-Natural		Brookley-Natural		Seasonal	Seasonal
Taxa	Total	% AH	Total	% BH	Total	% AN	Total	% BN	Total	Distribution
Mediomastus (LPIL)	381	63.5	4	20	210	45.0	196	51.7	791	54
Hobsonia florida	44	7.3	1	5	108	23.1	88	23.2	241	16.4
Capitella (LPIL)	95	15.8	-	-	3	0.6	3	0.8	101	6.9
Streblospio (LPIL)	18	3.0	2	10	21	4.5	4	1.1	45	3.1
Macoma mitchelli	26	4.3	-	-	9	1.9	4	1.1	39	2.7
Tubificidae (LPIL)	-	-	-	-	22	4.7	13	3.4	35	2.4
Nemertea 1 (LPIL)	11	1.8	-	-	8	1.7	13	3.4	32	2.2
Lepidactylus (LPIL)	-	-	-	-	27	5.8	-	-	27	1.8
Parandalia americana	5	0.8	-	-	9	1.9	16	4.2	30	1.7
Ameroculodes (LPIL)	-	-	-	-	18	3.9	6	1.6	24	1.6
Mulinia lateralis	3	0.5	-	-	4	0.9	17	4.5	24	1.6
Chironomidae (LPIL)	3	0.5	3	15	7	1.5	10	2.6	23	1.6
Nemertea 2 (LPIL)	12	2.0	-	-	5	1.1	3	0.8	20	1.4
Gastropoda (LPIL)	1	0.2	4	20	3	0.6	1	0.3	9	0.6
Polydora cornuta	-	-	-	-	4	0.9	2	0.5	6	0.4
Grandidierella bonneroides	-	-	-	-	3	0.6	-	-	3	0.2
Harpacticoida (LPIL)	-	-	-	-	3	0.6	-	-	3	0.2
Ischadium recurvum	-	-	2	10	-	-	1	0.3	3	0.2
Americamysis bahia	1	0.2	1	5	-	-	-	-	2	0.14
Apocorophium (LPIL)	-	-	-	-	-	-	2	0.5	2	0.14
Edotea triloba	-	-	1	5	1	0.2	-	-	2	0.14
Hirudinea (LPIL)	-	-	1	5	1	0.2	-	-	2	0.14
Cumacea (LPIL)	-	-	-	-	1	0.2	-	-	1	0.07
Hargeria rapax	-	-	1	5	-	-	-	-	1	0.07

	Airport Hole		Brookley Hole		Airport-Natural		Brookley-Natural		Seasonal	Seasonal
Taxa	Total	% AH	Total	% BH	Total	% AN	Total	% BN	Total	Distribution
Gastropod	-	-	-	-	-	-	1	0.3	1	0.07
Total Animals	600	-	20	-	467	-	380	-	1467	-
Average. # Animals	120	-	4	-	156	-	126	-	-	-
Total # Taxa	12	-	10	-	20	-	16	-	-	-
Average # Taxa	8	-	2.8	-	13	-	11	-	-	-

Appendix Table 4. Summary of benthic abundance by species in numerical order for the fall (December 2011) prerestoration collection.

	Airport Hole		Brookley Hole		Airport-Natural		Brookley-Natural		Seasonal	Seasonal
Taxa	Total	%AH	Total	% BH	Total	% AN	Total	% BH	Total	Distribution
Mediomastus (LPIL)	149	54.6	13	20.6	190	47.3	147	40.4	499	45.3
Streblospio (LPIL)	33	12.1	24	38.1	32	8.0	49	13.5	138	12.5
Capitella (LPIL)	40	14.7	-	-	41	10.2	19	5.2	100	9.1
Macoma mitchelli	14	5.1	5	7.9	37	9.2	31	8.5	87	7.9
Tubificidae (LPIL)	-	-	-	-	27	6.7	18	5.0	45	4.1
Nemertea 2 (LPIL)	2	0.7	-	-	14	3.5	28	7.7	44	4.0
Glycinde solitaria	20	7.3	12	19.0	1	0.3	7	1.9	40	3.6
Nemertea 1 (LPIL)	5	1.8	2	3.2	13	3.2	16	4.4	36	3.3
Polydora (LPIL)	-	-	-	-	16	4.0	17	4.7	33	3.0
Ameroculodes (LPIL)	-	-	-	-	6	1.5	5	1.4	11	1.0
Hobsonia florida	4	1.5	-	-	4	1.0	3	0.8	11	1.0
Parandalia americana	-		-	-	5	1.2	6	1.7	11	1.0
Apocorophium (LPIL)	-	-	2	3.2	4	1.0	3	0.8	9	0.8
Grandidierella bonneroides	-	-	-	-	2	0.5	5	1.4	7	0.6
Nereis succinea	1	0.4	-	-	1	0.3	3	0.8	5	0.5
Mulinia lateralis	-	-	-	-	1	0.3	3	0.8	4	0.4

	Airport Hole		Brookley Hole		Airport-Natural		Brookley-Natural		Seasonal	Seasonal
Taxa	Total	%AH	Total	% BH	Total	% AN	Total	% BH	Total	Distribution
Harpacticoida (LPIL)	2	0.7	-	-	-	-	1	0.3	3	0.3
Hypereteone heteropoda	-	-	-	-	3	0.8	-	-	3	0.3
Paraprionospio pinnata	-	-	3	4.8	-	-	-	-	3	0.3
Nematoda (LPIL)	-	-	1	1.6	1	0.3	-	-	2	0.2
Gammarus mucronatus	1	0.4	-	-	-	-	1	0.3	2	0.2
Callinectes sapidus	-	-	-	-	1	0.3	-	-	1	0.1
Chironomidae (LPIL)	-	-	-	-	1	0.3	-	-	1	0.1
Cumacea (LPIL)	-	-	-	-	1	0.3	-	-	1	0.1
Edotea triloba	-	-	-	-	-	-	1	0.3	1	0.1
Hesionidae (LPIL)	1	0.34	-	-	-	-	-	-	1	0.1
Hirudinea (LPIL)	-	-	1	1.6	-	-	-	-	1	0.1
Lepidactylus (LPIL)	-	-	-	-	1	0.3	-	-	1	0.1
Mytilidae (LPIL)	1	0.4	-	-	-	-	-	-	1	0.1
Ostracoda (LPIL)	-	-	-	-	-	-	1	0.3	1	0.1
Total Animals	273	-	63	-	402	-	364	-	1102	-
Average. # Animals	55	-	12.6	-	134	-	121	-	-	-
Total # Taxa	14	-	9	-	22	-	20	-	-	-
Average # Taxa	7.8	-	4.8	-	15.7	-	15.3	-	-	-

Appendix Table 5. Summary of benthic abundance by species in numerical order for the spring (April 2013) postrestoration collection.

	Airport Hole		Brookley Hole		Brookley Natural		Seasonal	Seasonal
Taxa	Total	% AH	Total	% AN	Total	% BH	Total	Distribution
Mediomastus (LPIL)	244	28.7	37	12.7	563	53.1	844	38.3
Capitella (LPIL)	499	58.7	199	68.2	54	5.1	752	34.1
Streblospio (LPIL)	36	4.2	20	6.9	120	11.3	176	8.0
Hobsonia florida	6	0.7	2	0.7	115	10.8	123	5.6
Tubificidae (LPIL)	1	0.1	1	0.3	94	8.9	96	4.4
Chironomidae (LPIL)	17	2.0	10	3.4	13	1.2	40	1.8
Mulinia lateralis	2	0.2	-	-	35	3.3	37	1.7
Nemertea 1 (LPIL)	13	1.5	4	1.4	14	1.3	31	1.4
Macoma mitchelli	13	1.5	5	1.7	2	0.2	20	0.9
Polydora (LPIL)	-	-	-	-	17	1.6	17	0.8
Parandalia americana	9	1.1	1	0.3	3	0.3	13	0.6
Ameroculodes (LPIL)	1	0.1	-	-	11	1.0	12	0.5
Edotea triloba	1	0.1	-	-	10	0.9	11	0.5
Harpacticoida (LPIL)	2	0.2	7	2.4	-	-	9	0.4
Apocorophium (LPIL)	-	-	-	-	4	0.4	4	0.2
Grandidierella bonneroides	-	-	-	-	3	0.3	3	0.1
Hargeria rapax	1	0.1	2	0.7	-	-	3	0.1
Laeonereis culveri	2	0.2	1	0.3	-	-	3	0.1
Cumacea (LPIL)	-	-	1	0.3	1	0.1	2	0.1
Cladocera (LPIL)	-	-	1	0.3	-	-	1	0.1
Copepoda (LPIL)	1	0.1	-	-	-	-	1	0.1
Myrophis punctatus	-	-	1	0.3	-	-	1	0.1
Mysidacea (LPIL)	1	0.1	-	-	-	-	1	0.1
Nematoda (LPIL)	-	-	-	-	1	0.1	1	0.1

	Airport Hole		Brookley Hole		Brookley Natural		Seasonal	Seasonal
Taxa	Total	% AH	Total	% AN	Total	% BH	Total	Distribution
Nemertea 2 (LPIL)	1	0.1	-	-	-	-	1	0.1
Ostracoda (LPIL)	-	-	-	-	1	0.1	1	0.1
Total Animals	850	-	292	-	1061	-	2203	-
Average. # Animals	170	-	58	-	354	-	-	-
Total # Taxa	18	-	15	-	18	-	-	-
Average # Taxa	8.6	-	7.8	-	14.3	-	-	-

Appendix Table 6. Summary of benthic abundance by species in numerical order for the summer (August 2013) postrestoration collection.

	Airport Hole		Brookley Hole		Airport-Natural		Brookley-Natural		Seasonal	Seasonal
Taxa	Total	% AH	Total	% BH	Total	% AN	Total	% BN	Total	Distribution
Mediomastus (LPIL)	296	76.7	394	77.4	134	33.7	207	47.6	1031	59.7
Tubificidae (LPIL)	1	0.3	-	-	140	35.2	67	15.4	208	12.0
Streblospio (LPIL)	48	12.4	57	11.2	30	7.5	41	9.4	176	10.2
Hobsonia florida	8	2.1	14	2.8	34	8.5	36	8.3	92	5.3
Capitella (LPIL)	7	1.8	22	4.3	5	1.3	7	1.6	41	2.4
Nemertea 1 (LPIL)	5	1.3	8	1.6	8	2.0	8	1.8	29	1.7
Mulinia lateralis	2	0.5	1	0.2	10	2.5	10	2.3	23	1.3
Americamysis bahia	7	1.8	3	0.6	4	1.0	3	0.7	17	1.0
Ameroculodes (LPIL)	1	0.3	1	0.2	7	1.8	8	1.8	17	1.0
Apocorophium (LPIL)	-	-	-	-	1	0.3	15	3.5	16	0.9
Chironomidae (LPIL)	1	0.3	3	0.6	2	0.5	4	0.9	10	0.6
Grandidierella bonneroides	-	-	-	-	6	1.5	4	0.9	10	0.6
Lepidactylus (LPIL)	-	-	-	-	7	1.8	-	-	7	0.4
Gastropoda (LPIL)	2	0.5	-	-	4	1.0	-	-	6	0.4
Ischadium recurvum	-	-	-	-	-	-	6	1.4	6	0.4

	Airport Hole		Brookley Hole		Airport-Natural		Brookley-Natural		Seasonal	Seasonal
Taxa	Total	% AH	Total	% BH	Total	% AN	Total	% BN	Total	Distribution
Edotea triloba	-	-	-	-	1	0.3	4	0.9	5	0.3
Macoma mitchelli	2	0.5	3	0.6	-	-	-	-	5	0.3
Nereis succinea	-	-	-	-	2	0.5	3	0.7	5	0.3
Parandalia americana	-	-	1	0.2	-	-	4	0.9	5	0.3
Cerapus (LPIL)	-	-	-	-	2	0.5	2	0.5	4	0.2
Ephemeroptera (LPIL)	3	0.8	1	0.2	-	-	-	-	4	0.2
Polydora (LPIL)	-	-	-	-	-	-	3	0.7	3	0.2
Gammarus mucronatus	1	0.3	-	-	-	-	1	0.2	2	0.1
Nemertea 2 (LPIL)	-	-	-	-	-	-	2	0.5	2	0.1
Callinectes sapidus	-	-	-	-	1	0.3	-	-	1	0.1
Crab megalops (LPIL)	1	0.3	-	-	-	-	-	-	1	0.1
Crab Zoea (LPIL)	-	-	1	0.2	-	-	-	-	1	0.1
Penaeus setiferus	1	0.3	-	-	-	-	-	-	1	0.1
Total Animals	386	-	509	-	398	-	435	-	1728	-
Average # Animals	77	-	102	-	133	-	145	-	-	-
Total # Taxa	16	-	13	-	18	-	17	-	-	-
Average # Taxa	7.2	-	7.4	-	11	-	14	-	-	-

Appendix Table 7. Summary of fish species composition. (Yellow = numerically dominant species; Blue = Species present during all sampling events.).

			Brookley Hole								Airport Hole							
			Au	De	Ap	Oc	Ap	Au	T	T	Au	De	Ap	Oc	Ap	Au	T	T
Common Name	*Species*	**Family**	P	P	P	Y1	Y1	Y1	P	Y1	P	P	P	Y1	Y1	Y1	P	Y1
Striped Anchovy	*Anchoa hapsetus*	Engraulidae	X	-	-	-	-	X	X	-	-	-	-	-	-	-		
Bay Anchovy	*Anchoa mitchilli*	Engraulidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Hardhead Catfish	*Arius felis*	Ariidae	X	-	-	X	X	X	X	X	X	-	-	X	-	X	X	X
Gafftopsail	*Bagre marimus*	Ariidae	X	-	-	-	-	X	X	X	-	-	-	-	-	X	-	X
Silver Perch	*Bairdiella chrysoura*	Bidyanus	X	X	-	-	-	-	X	-	X	-	-	-	-	-	X	X
White Trout	*Cynoscion arenarius*	Salmonidae	X	-	-	X	-	X	X	X	X	-	X	X	-	X	X	X
Gulf Menhaden	*Brevoortia patronus*	Clupeidae	X	-	-	X	-	X	X	X	X	-	X	-	-	X	X	X
Threadfin shad	*Dorosoma petenense*	Clupeidae	X	X	-	-	-	X	X	X	X	X	-	-	X	X	X	X
Scaled Sardine	*Harengula jaguana*	Clupeidae	X	-	-	-	-	-	X	-	-	-	-	X	-	-	-	-
Banded Drum	*Larimus faciatus*	Sciaenidae	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spot	*Leiostomus xanthurus*	Sciaenidae	X	X	-	-	-	-	X	X	X	X	-	X	-	X	X	X
Atlantic Croaker	*Micropogonias undulatus*	Sciaenidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Juvenile Drum	*Sciaenidae spp.*	Sciaenidae	-	-	X	-	-	-	X	-	-	X	X	-	-	-	X	-
Black Drum	*Pogonias cromis*	Sciaenidae	-	-	-	-	-	-	X	-	-	-	X	-	-	-	X	-
Atlantic Moonfish	*Selene setapinnis*	Molidae	X	-	-	-	-	-	X	-	X	-	-	-	-	-	X	-
Atl. Cutlassfish	*Trichiurus lepturus*	Trichiuridae	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-
Searobin	*Triglidae spp.*	Triflidae	-	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-
Harvestfish	*Peprilus alepidotus*	Stromateidae	-	-	-	-	-	-	-	-	X	-	-	-	-	-	X	-
Butterfish	*Peprilus triacanthus*	Stromateidae	-	-	-	-	-	-	-	-	-	X	-	-	-	-	X	-
Goby	*Gobiidae spp.*	Gobiidae	-	-	-	-	-	-	-	-	-	X	-	-	-	-	X	-
Pigfish	*Lagodon rhomboides*	Sparidae	-	-	-	-	-	-	-	-	X	-	-	-	-	-	X	-
Atlantic Bumper	*Chloroscombrus chrysurus*	Carangidae	-	-	-	-	-	-	-	-	X	-	-	-	-	-	X	-
Jack Crevalle	*Caranx hippos*	Carangidae	-	-	-	-	-	X	-	X	X	-	-	-	-	-	X	-

Common Name	*Species*	Family	Brookley Hole								Airport Hole							
			Au	De	Ap	Oc	Ap	Au	T	T	Au	De	Ap	Oc	Ap	Au	T	T
			P	P	P	Y1	Y1	Y1	P	Y1	P	P	P	Y1	Y1	Y1	P	Y1
Blue Crab	*Callinectes sapidus*	Portunidae	X	X	-	-	-	X	X	X	X	-	-	-	-	-	X	-
Brown Shrimp	*Penaeus aztecus*	Crangonidae	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-
White Shrimp	*Penaeus setiferus*	Penaeidae	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Squid	*Lolliguncula brevis*		X	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-
Mud Crab	*Rhithropanopeus harrisii*	Xanthidae	-	-	-	-	-	-	-	-	-	X	-	-	-	-	X	-
Eastern Oyster	*Crassostrea virginica*	Ostreidae	-	-	X	-	-	-	X	-	-	X	X	X	X	X	X	X
Species Total			15	9	7	6	4	11	21	11	15	10	8	8	5	10	21	11
Families Total			10	7	6	6	4	8	14	8	12	8	6	7	5	7	15	8
# Fish Species			12	7	4	5	3	9	16	9	13	7	6	6	3	8	17	9
# Fish Families			7	5	3	5	3	6	9	6	10	5	4	8	3	5	11	6
# Crustaceans			2	2	2	1	1	2	3	2	2	2	1	1	1	1	3	1
# Mollusks			1	0	1	0	0	0	2	0	0	1	1	1	1	1	1	1

Legend: Au = August; De = December; Ap = April; Oc = October; T = Total; P = Prerestoration; Y1 = Year 1 Postrestoration

Appendix Table 8. Summary of species composition and CPUE rates from otter trawls in Brookley Hole. (Yellow = Highest CPUE; Green = Species with relatively high CPUE taken from both borrow pits; Orange = Species with CPUE most dissimilar between borrow pits).

	Prerestoration						Postrestoration						Overall PRE		Overall POST	
Common Name	Aug	CPUE	Dec	CPUE	Apr	CPUE	Oct	CPUE	Apr	CPUE	Aug	CPUE	Total	CPUE	Total	CPUE
Atl. Croaker	10	20	125	250	10	40	3	6	28	56	9	27	145	193	40	117
Atl. Cutlassfish	-	-	-	-	1	4	-	-	-	-	-	-	1	1.3	-	-
Atlantic Moonfish	2	4	-	-	-	-	-	-	-	-	-	-	2	2.7	-	-
Banded Drum	-	-	1	2	-	-	-	-	-	-	-	-	1	1.3	-	-
Bay Anchovy	56	112	25	50	3	12	89	191	6	12	38	114	84	112	133	102
Blue Crab	6	12	8	16	-	-	-	-	-	-	1	3	14	19	1	0.8
Brown Shrimp	-	-	-	-	5	20	-	-	-	-	-	-	5	6.7	-	-
Eastern Oyster	-	-	-	-	1	4	-	-	-	-	-	-	1	1.3	-	-
Gafftopsail Catfish	1	2	-	-	-	-	-	-	-	-	1	3	1	1.3	1	0.8
Gulf Menhaden	1	2	-	-	-	-	1	2	-	-	6	18	1	1.3	7	5.4
Hardhead Catfish	7	14	-	-	-	-	1	2	3	6	1	3	7	9.3	5	3.8
Juvenile Drum	-	-	-	-	44	176	-	-	-	-	-	-	44	58.7	-	-
Mud Crab	-	-	3	6	-	-	-	-	-	-	-	-	-	-	-	-
Searobin	-	-	-	-	-	-	-	-	-	-	-	-	2	2.7	-	-
Scaled Sardine	1	2	-	-	-	-	-	-	-	-	-	-	1	1.3	-	-
Silver Perch	4	8	1	2	-	-	-	-	-	-	-	-	5	6.7	-	-
Striped Anchovy	1	2	-	-	-	-	-	-	-	-	-	-	1	1.3	-	-
Spot	17	34	25	50	-	-	-	-	-	-	3	9	42	56	3	3.2
Squid	1	2	-	-	-	-	-	-	-	-	-	-	1	2.7	-	-
Threadfin Shad	40	80	1	2	-	-	-	-	-	-	13	39	41	54.7	13	10.2
White Shrimp	696	1392	13	26	47	188	138	296	107	214	8	24	756	1014	253	194
White Trout	6	12	-	-	-	-	1	2	-	-	4	12	6	8	5	4.1
Jack Crevalle	-	-	-	-	-	-	-	-	-	-	1	3	-	-	1	0.8
Total Captures	849	-	202	-	110	-	233	-	144	-	85	-	1161	-	462	-

Appendix Table 9. Summary of species composition and CPUE rates from otter trawls in Airport Hole. (Yellow = Highest CPUE; Green = Species with relatively high CPUE taken from both borrow pits; Orange = Species with CPUE most dissimilar between borrow pits).

	Prerestoration						Postrestoration						Overall PRE		Overall POST	
Common Name	Aug	CPUE	Dec	CPUE	Apr	CPUE	Oct	CPUE	Apr	CPUE	Aug	CPUE	Total	CPUE	Total	CPUE
Atlantic Croaker	31	62	1	2	8	32	7	26	16	56	6	22.5	40	67.5	29	36.3
Atlantic Moonfish	1	2	-	-	-	-	-	-	-	-	-	-	1	1.3	-	-
Atlantic Bumper	2	4	-	-	-	-	-	-	-	-	-	-	2	2.7	-	-
Bay Anchovy	74	148	47	94	8	32	120	450	23	81	47	176	129	172	190	237.5
Black Drum	-	-	-	-	1	4	-	-	-	-	-	-	1	1.3	-	-
Butterfish	-	-	1	2	-	-	-	-	-	-	-	-	1	1.3	-	-
Blue Crab	1	2	-	-	-	-	-	-	-	-	-	-	1	1.3	-	-
Eastern Oyster	-	-	10	20	2	-	13	52	1	3.5	2	7.4	12	16	16	20.8
Gafftopsail Catfish	-	-	-	-			-	-	-	-	2	7.4	-	-	2	2.5
Goby	-	-	1	2	-	-	-	-	-	-	-	-	1	1.3	-	-
Gulf Menhaden	1	2	-	-	1	4	-	-	-	-	3	11.2	2	2.7	3	3.8
Hardhead Catfish	3	6	-	-	-	-	6	23	-	-	2	7.4	3	4	8	10.1
Harvestfish	1	2	-	-	-	-	-	-	-	-	-	-	1	1.3	-	-
Jack Crevalle	1	2	-	-	-	-	-	-	-	-	-	-	1	1.3	-	-
Juvenile Drum	-	-	2	4	51	204	-	-	-	-	-	-	53	70.7	-	-
Mud Crab	-	-	3	6	-	-	-	-	-	-	-	-	3	4	-	-
Pigfish	1	2	-	-	-	-	-	-	-	-	-	-	1	1.3	-	-
Scaled Sardine	-	-	-	-	-	-	1	4	-	-	-	-	-	-	1	1.3
Silver Perch	6	12	-	-	-	-	-	-	-	-	-	-	6	8	-	-
Spot	46	92	8	16	-	-	1	4	-	-	7	26.3	54	72	6	7.5
Squid	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Threadfin Shad	34	68	2	4	-	-	-	-	1	3.5	19	71	36	48	20	29.3
White Trout	3	6	-	-	4	16	9	34	-	-	2	7.5	7	9.3	11	13.9
White Shrimp	49	98	10	20	24	96	128	480	32	113	4	15	83	110.7	164	213.2
Total Captures	254	-	85	-	99	-	285	-	73	-	94		438	-	452	

Appendix Table 10. Prerestoration fisheries acoustic data summary.

Month	Site	STF	Length (cm)			Fish Depth (m)		Pit Depth (m)		Fish Density per100 m³			Est. # Fish
			ML	MX	AV	AV	MX	AV	MX	TD	MTD	HDL	
Aug	BH	1137	4.0	43	11	-3.6	-5.5	-5.4	-6.8	60.4	171	C	7788
	AH	52	4.8	22	9	-3.0	-3.7	-2.7	-4.0	13.2	21	S	270
Dec	BH	508	4.7	40	12	-4.6	-6.4	-5.3	-6.6	8.20	41	C	4267
	AH	22	5.0	18	10	-2.6	-3.0	-2.8	-3.6	29.9	313	NC	3248
Apr	BH	111	5.9	46	19	-4.2	-5.8	-4.7	-6.7	11.4	21	N	2330
	AH	20	4.7	23	12	-2.9	-3.6	-2.5	-3.6	18.5	49	C	116

Appendix Table 11. Postrestoration fisheries acoustic data summary.

Month	Site	STF	Length (cm)			Fish Depth (m)		Pit Depth (m)		Fish Density per100 m³			Est. # Fish
			ML	MX	AV	AV	MX	AV	MX	TD	MTD	HDL	
Aug	BH	18	6.6	16	9.3	-2.7	-3.7	-2.7	-3.8	9.8	18	S	385
	AH	36	5.2	12	27.5	-2.7	-3.6	-2.8	-3.9	5.9	14	N	673
Oct	BH	10	4.9	8	6.4	-2.0	-2.1	-2.1	-2.5	23.9	62	N	570
	AH	151	4.5	25	9.0	-2.9	-3.2	-2.6	-3.8	39.8	175	C	2605
Apr	BH	19	7.4	27	13.7	-2.4	-3.4	-2.8	-3.7	4.2	22	C	457
	AH	15	6.8	13	10	-2.2	-3.5	-2.7	-3.8	3.0	7	N	229

Legend

ML = Minimum Fish Length; MX = Maximum Fish Length; AV = Average Fish Length ; STF = Single Target Fishes; DOB = Depth off Bottom; TD = Total Density; MTD = Maximum Transect Density; HDL = Highest Density Location; S = Southern sector of borrow pit; N = Northern sector of borrow pit; C = Central Sector of borrow pit

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14. ABSTRACT
Many inshore coastal habitats have been altered by sand excavation for commercial and beach nourishment purposes, producing artificial holes and depressions. These features are characterized by poor sediment, water quality, altered circulation patterns, water column stratification, and the accumulation of fine sediments. These parameters are frequently cited as factors for degraded habitat found in borrow pits. This report summarizes the results of baseline and Year 1 post-restoration monitoring of Brookley (partially restored) and Airport Holes (control), located in Mobile Bay, Alabama. Monitoring efforts included a combination of fisheries acoustic techniques to determine fish density and spatial and temporal distribution patterns, conventional fisheries to determine species composition, length, CPUE, water quality, and sediment grain size analysis. Benthic macroinvertebrates were sampled seasonally to evaluate recruitment and community structure. Postrestoration results indicated a significant improvement in water quality conditions in Brookley Hole. Hypoxic/anoxic conditions present during prerestoration were absent during postrestoration sampling. Prerestoration infaunal sampling indicated that both holes supported impoverished benthic assemblages comprised largely of opportunistic, disturbance-adapted infauna. Species abundance increased significantly during postrestoration sampling; however was still depressed when compared to the surrounding bay waters. One contributing factor is that water depths in Brookley Hole are still greater than the surrounding bay waters. There was no significant difference in abundance, taxa, or species composition among sites or the pre- and postplacement time periods, indicating that finfish utilization was not affected by the placement of dredged material. Brookley Hole remains a suitable candidate for either partial or complete filling with dredged material.

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